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New York

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JOURNAL

of the

AMERICAN WELDING SOCIETY

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Volume 9 OCTOBER, 1930 Number 10

TABLE OF CONTENTS

Society and Related Activities

	Page
Fall Meeting	3
Samuel Wylie Miller Memorial Medal	3
Award of Miller Memorial Medal	3
Second Lincoln Arc Welding Prize Competition	4
In Memoriam	5
Gas Products Association Meeting	5
Next Fall Meeting	6
New Building Code	6
Special Meeting New York Section	6
Section Activities	6
Employment Service Bulletin	7

Technical Papers, Items and Reports

Electric Arc Welding of Aluminum, by W. M. Dunlap	8
Physical Properties of Electrically Welded Steel Tubing, by H. L. Whittemore, J. S. Adelson and E. O. Sequist	17
A Study of Welded Metals Under Fatigue Tests, by G. E. Thornton	48
Suggested Revision Bulletin on "Standard Tests for Welds"	67
Bend Tests, by W. B. Miller	75
Tensile Tests for Welds, by J. W. Owens	79
The Elimination of Joints in Open Track, by J. H. Deppeler	88
The Application of Fusion Welding to Pressure Vessels, by J. C. Hodge	93
Shear Tests for Welds, by Andrew Vogel	117
Why the Piping Contractor Prefers a Welded Job, by John J. Love	121
Current Welding Literature	125

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Fall Meeting

One of the largest and most successful national meetings of the American Welding Society was held in Chicago during the week of September 22, in conjunction with the Metal Exposition. About 400 people officially registered. Twenty-two technical papers were presented at six technical sessions.

An inspection trip was arranged on Thursday morning, September 25, to the Hawthorne Works of the Western Electric Company. The visitors were conducted through welding installations which incorporated the use of automatic, semi-automatic and manual welding equipment. Other departments were also visited.

The work of the American Bureau of Welding was featured prominently through a meeting of the Bureau, Structural Steel Welding Committee, presentation of papers resulting from the fundamental research investigations at various universities and a symposium by the Committee on Standard Tests for Welds.

The Board of Directors held their semi-annual meeting on Monday evening. Among the important matters discussed were the selection of Boston as the place for the 1931 fall meeting, and approval of the publication of the new building code.

The welding exposition was arranged as part of the National Metal Exposition at the Stevens Hotel. It is estimated that some fifty thousand people viewed the exhibits.

Ladies' entertainment included a luncheon, sight-seeing trip through Chicago's parks and places of interest, a trip to the Chicago Art Museum, and a luncheon and style show at Marshall Field & Company.

The annual banquet and dance of the A. W. S. was held in the Gold Room of the Congress Hotel. About 300 members and their guests were present. At the dinner, Mr. James W. Owens was presented the Samuel Wylie Miller Memorial Medal for 1929 for his conspicuous work in extending the applications of welding in marine construction.

Considerable credit is due to the Chicago Section and its special committees for the smoothness of operations and the success of many of the features of the fall meeting.

Samuel Wylie Miller Memorial Medal

A Correction

In the Year Book of the Society which appeared as the August, 1930; issue of the JOURNAL, an error was made in printing the present conditions of award of the Miller Medal. During the lifetime of Mr. Miller the award was restricted to achievement in fusion and welding cutting, but when the medal was perpetuated as a memorial to Mr. Miller, its scope was extended to all processes of welding and cutting. The present conditions, as given on page 17 of the August, 1930, issue, should be corrected to read as follows:

1. The Samuel Wylie Miller Memorial Medal shall be awarded annually for any meritorious achievement which, in the judgment of the Miller Medal Board of Trustees, has contributed conspicuously to the advancement of the art of welding and cutting.
2. Individuals only, but of any country and of any age, shall be eligible for the award.
3. The award for any calendar year shall be announced and the medal, together with a suitable certificate, presented at an annual meeting following the year for which the award is made.

Report of Miller Memorial Medal Board of Trustees

The Samuel Wylie Miller Memorial Medal for the year 1929 is awarded to James Whitfield Owens.

Mr. Owens for many years has been prominent in the development of the welding art in this country.

As Welding Aide for the Bureau of Construction and Repair of the Navy, he organized the first welding shop in the Navy, introduced certification tests for welders employed in the construction of naval vessels and prepared the welding specifications for the scout cruisers then under construction. As Director of Welding of the Newport News Shipbuilding and Dry Dock Company, he was responsible for a marked increase in the application of welding as a tool in the fabrication of merchant ships. His keen interest and energetic activity as Chairman of the American Welding Society Committee on Nomenclature, Definitions and Symbols was largely responsible for the promulgation of the first comprehensive standard definitions, nomenclature and symbols for the welding industry.

During and since the days of the Welding Committee of the Emergency Fleet Corporation, he has been an energetic and enthusiastic investigator who has contributed freely to the industry the results of his extensive studies.

In 1928 Mr. Owens was awarded in international competition the Lincoln Prize, sponsored by the American Society of Mechanical Engineers.

The Board of Trustees considers that these various contributions to the advancement of the welding art constitute a conspicuous achievement worthy of the Samuel Wylie Miller Memorial Medal.

Second Lincoln Arc Welding Prize Competition Is Announced

Designers and engineers in every industry, where iron and steel forms all or a part of the manufactured product, are again given the opportunity by The Lincoln Electric Company, Cleveland, Ohio, sponsors of the Second Lincoln Arc Welding Prize Competition, to show their skill and ingenuity in utilizing the advantages of arc-welded construction. As a reward for their efforts seventeen thousand five hundred dollars will be awarded for the forty-one best papers submitted in the competition. The Jury of Awards, who will judge the papers entered in the competition, will be composed of the Electrical Engineering Department of Ohio State University under chairmanship of Professor Erwin E. Dreese and such others as he may select.

In announcing this competition, which is the second to be sponsored by The Lincoln Electric Company, the sponsors are establishing a biennial competition which should be welcomed by industrial engineers and manufacturing executives throughout the world. The purpose of this Second Lincoln Arc Welding Prize Competition, as announced by its sponsors, is to stimulate designers and engineers in every line of industry to think of the manufacture of their own products by the use of arc welding and to increase their knowledge of the feasibility of its application.

The forty-one prizes, to be given by The Lincoln Electric Company to the winners as selected by the Jury of Awards, are: For the first prize paper, $7,500; for the second prize paper, $3,500; for third prize paper, $1,500; for fourth prize paper, $750; for fifth prize paper, $500; for sixth prize paper, $250; and for the seventh to forty-first prize papers, $100 each.

The competition, as announced, will be open to any person in the world except the employees of the sponsors. The closing date for the competition will be October 1, 1931. Other details of the rules of the competition are expected to be announced shortly.

In Memoriam

At a meeting of the Executive Committee of the American Welding Society held in the Engineering Societies Building, New York, N. Y., on the ninth day of September, 1930, the following resolution was unanimously adopted:

Resolved, That the American Welding Society record, with the deepest regret, the loss which they and the engineering profession at large have sustained by the death of Thomas Shipley on January 22, 1930.

As a Charter Member of the Society, a member of the Philadelphia Section since its organization, and holder of the sustaining membership of the York Ice Machinery Corporation, he was a most faithful worker and was always keenly alive to the best interests of the Society.

The high esteem in which Mr. Shipley was held by his friends, his business associates, by the members of the Society, and by all who knew him well, is a tribute accorded only to those whose character contains elements of sterling worth. He exhibited in the highest degree those qualities that engineers should emulate; he was steadfast, dependable, energetic, loyal, unbiased in judgment and progressive in spirit. He was of kindly personality, genial and considerate of others.

In his passing, the American Welding Society loses one who steadfastly upheld the best aims and traditions of the profession, and its members lose a valued friend, who was a friend to all.

E. A. DOYLE,
President.

Sept. 9, 1930.

At a meeting of the Executive Committee of the American Bureau of Welding, held in the Engineering Societies Building on the twenty-second day of August, 1930, the following resolutions were unanimously adopted:

Whereas: The Executive Committee of the American Bureau of Welding has learned with profound sorrow of the death on August 14 of JAMES H. EDWARDS, a member of the Bureau and Chief Engineer of the American Bridge Company, and

Whereas: The members and officials of the American Bureau of Welding recall with deep appreciation the helpful interest that Mr. Edwards always took in its affairs and, in particular, the able and inspiring guidance that he gave as Chairman of its Structural Steel Welding Committee, and

Whereas: It is realized that the passing of this true-hearted man will leave an unfillable vacancy in the ranks of his fellow engineers and his associates as friends; therefore be it

Resolved: That the members of the Executive Committee of the American Bureau of Welding hereby express their deep regret and sense of personal loss in the death of James H. Edwards and their appreciation of his services to the American Bureau of Welding, and, further, be it

Resolved: That these resolutions be spread upon the records of the Bureau and that copies be sent to his family and to his associates in the American Bridge Company as an expression of our mutual loss and sympathy.

C. A. ADAMS,
Director.

W. SPRAGUEN,
Secretary.

Gas Products Association Meeting

At the annual meeting of the Gas Products Association, E. L. Mills, sales manager of the Bastian Blessing Company, was elected as president.

In its educational work the Association has prepared some motion picture films which portray the development of oxy-acetylene welding with particular reference to pipe welding and fuselage construction. These will be available as required for welding meetings and symposiums.

Special Meeting, New York Section

A special meeting of the New York Section of the American Welding Society has been arranged for Tuesday evening, 8 o'clock, Nov. 18, in the Engineering Societies Building, 33 West Thirty-ninth Street, by the Committee on Building Codes. The subject will be "Why Structural Welding Should Be Recognized by the Building Department." In addition to the greetings of the New York Section chairman, there will be an introductory address by President Doyle setting forth the work of the Society in the matter of codes. This will be followed by a description of the Society's code and the extent of its adoption, by Professor F. P. McKibben, and a statistical report of existing welding tonnage, by Gilbert D. Fish.

Following these there will be an illustrated lecture showing the applications of structural welding in buildings and bridges throughout the United States, presented by representatives of the General Electric, Westinghouse Electric, Lincoln Electric, Linde Air Products, and American Bridge companies, and a number of others.

There will be a number of special guest speakers to be announced later. It is planned that this meeting will be instrumental in crystallizing opinion as to the adoption of welding in city codes.

Next Fall Meeting

Aa a Board of Directors' meeting held in connection with the Fall Meeting of the Society in Chicago it was unanimously decided to hold the next Fall Meeting in Boston. As in other years, there will be an exposition held jointly with the A. S. S. T. Other technical societies are planning to hold sessions at the same time.

Revised Building Code

A revised edition of the Building Code of the American Welding Society is now available for distribution. The pamphlet containing the Code, also, includes as an appendix, such supplementary information as to make the document complete. In a previous issue of the Code it was necessary to refer to the various bulletins of the Structural Steel Welding Research Committee. Copies of the new Code are available at 25c. per copy with special rates for quantity lots.

Section Activities

Boston

The first meeting of the season will be held at the plant of the Austin Hastings Company, Incorporated, 226 Binney Street, Cambridge, on Friday evening, October 24 at 7:30 p. m. The details of this meeting will be announced later. As this is the opening of the season, it is hoped that as many as possible will attend the meeting.

In November the Section will visit the Thomson-Gibb Electric Welding Company in Lynn. Announcement as to the nature of the demonstrations which will be held, and the names of the speakers, together with the subjects they will speak on, will be made very soon.

As far as possible the Section plans to hold its meetings on the third Friday of each month.

Los Angeles

A very successful meeting of this Section was held on Sept. 18. A short executive committee meeting was held before the dinner and it was resolved that the second Thursday in each month would be reserved for the Society meetings during the coming season. The talk given by James W. Foley, nationally known poet and humorist, proved to be one of the outstanding events of the evening. Robert G. Wulf, chemical engineer, gave an interesting technical talk on "The Chemistry of Oxy-Acetylene Welding and Cutting."

The October meeting will be on the second Thursday of October at the usual place. C. W. Martin, welding supervisor, Western Pipe & Steel Company, will give an illustrated talk on "Weld Stresses." It is also hoped to have Paul Jeffers, professional engineer, tell about the A. W. S. meeting in Chicago; and to have a short talk from Professor F. W. Maxstadt, California Institute of Technology, on "Magnetic Influence."

New York

On Sept. 16 the members of the

New York Section met at the Westinghouse Lighting Institute, Grand Central Palace, where they inspected the "City of Light." Gilbert D. Fish, consulting structural engineer, Westinghouse Electric & Manufacturing Company, spoke on the "Recent Developments in Electric Welding of Structural Steel." John J. Crowe, Air Reduction Company, gave a talk on "The Flame Cutting of Steel."

Philadelphia

The October meeting of the Philadelphia Section will be held on the 20th. John Reed, chief electrical engineer, Bethlehem Steel Company, is to present a paper entitled "Illustrations of Repairs to Steel Plant Machinery Done by Welding." H. J. Bowles, welding supervisor, Bethlehem Steel Company, will exhibit some slides of a number of unusual welding jobs and will talk on "Instruction and Qualifications of Welders."

San Francisco

The September meeting was held on the 26th. Messrs. Griffiths and Henderson of the Lincoln Electric Company spoke on the latest developments in Carbon Arc Welding. This talk covered the mechanical as well as manual developments of this process.

EMPLOYMENT SERVICE BULLETIN

Opportunities.—The Society is glad to learn of desirable opportunities from responsible sources, announcements of which will be published without charge in the BULLETIN.

Services Available.—Under this heading brief announcements (not more than seventy-five words in length) will be published without charge to members. Announcements will not be repeated except upon request received after an interval of three months; during this period, names and records will remain in the office reference files.

Note.—Copy for publication in the BULLETIN should reach the Society's Office not later than the thirtieth of the month if publication in the following issue is desired. *ALL REPLIES should be addressed to the number indicated in each case and mailed to the Society headquarters.*

SERVICES AVAILABLE

A-104. Mechanical Engineer with past machine shop and sales engineering experience, has for four years specialized on technical publicity, mainly in connection with welding, with marked success. Desires position in technical publicity, editorial or sales field.

A-105. Electric arc welder with eleven years' experience seeks steady position with reliable concern.

A-106. Welder with several years' experience acetylene welding pipe and in job shop.

A-107. Welder with ten years' experience with electric arc and acetylene on tanks, boilers, sheet metals, etc., desires position in Chicago. Can use own judgment. Am skilled operator.

A-108. Engineer desires position. Has had technical education as electrical engineer 4½ years with G. E. Company. Experience in electrical contracting work and salesman in welding industry; then became General Purchasing Agent for a large independent manufacturer of oxy-acetylene equipment and supplies.

Electric Arc Welding of Aluminum

By W. M. Dunlap†

FUSION welding has been divided into two general classes: torch welding and arc welding. The fusion welding of aluminum and its alloys by means of an oxy-hydrogen or oxy-acetylene torch is an art that has been known and practiced for the past fifteen or twenty years by metal workers engaged in the fabrication of aluminum articles. During the past year much information concerning the torch and spot welding of aluminum and its alloys has been published in the various technical journals. However, insofar as the author has been able to determine, there has been nothing published concerning the arc welding of the above metals. The consensus of opinion seems to be that aluminum cannot be arc welded. This opinion was entirely correct until a very few months ago. During the past few months rather extensive investigations of the application of the arc welding process to aluminum have been conducted in the Aluminum Research Laboratories of the Aluminum Company of America under the supervision of the author. As a result of this work, the process has been developed to the point where, within certain limits, it may be considered practical as a production method. At the present time the successful commercial arc welding of aluminum and its alloys is being done by several metal fabricating plants.

The arc welding process is divided into two classes: Metallic arc, or Slavianoff process and carbon arc, or Bernardos process. Both of these methods are coming into use for welding aluminum; however, the former process only will be discussed in this paper.

Electric arc welding dates back to about 1881 and the general principles of the process are well known. This paper will discuss the application of these principles to the welding of aluminum. The first principle involved in this case consists chiefly in the heating of the work to a welding temperature by means of an electric arc produced or "struck" between the work and a metallic electrode. The electrode melts and feeds into the joint, thus supplying the material required to complete the weld. The arc serves three distinct purposes: it supplies heat to melt the edges of the joint, heat to melt the electrode metal, and it carries the metal from the electrode to the weld. The electrode serves two purposes: it constitutes a portion of the electrical circuit, and is a source of filler metal for the weld.

Equipment Used for Arc Welding Aluminum

The equipment required for arc welding aluminum is practically the same as that used for similar work on other metals and consists of: a

*Paper presented at Fall Meeting, A.W.S., Chicago, Ill., September, 1930.

†Aluminum Research Laboratories, Aluminum Company of America, New Kensington, Pa.

welding generator, a pair of lead cables, an electrode holder, a ground clamp, an operator's helmet or shield, and a supply of electrodes.

The generator should be a variable voltage machine with a current rating of from 50 to 200 or 300 amp. and an open circuit (striking) voltage of about 60 volts. It may have any one of the common types of drive—electric motor, gasoline motor, or belt—but for a small single operator unit it will be found more practicable to have a portable motor-generator set. It will be found best to secure a machine which the manufacturer has designated to hold a stable arc at low currents, and in addition, it is suggested that a stabilizing resistance be secured with the machine if it is to be used on light work.

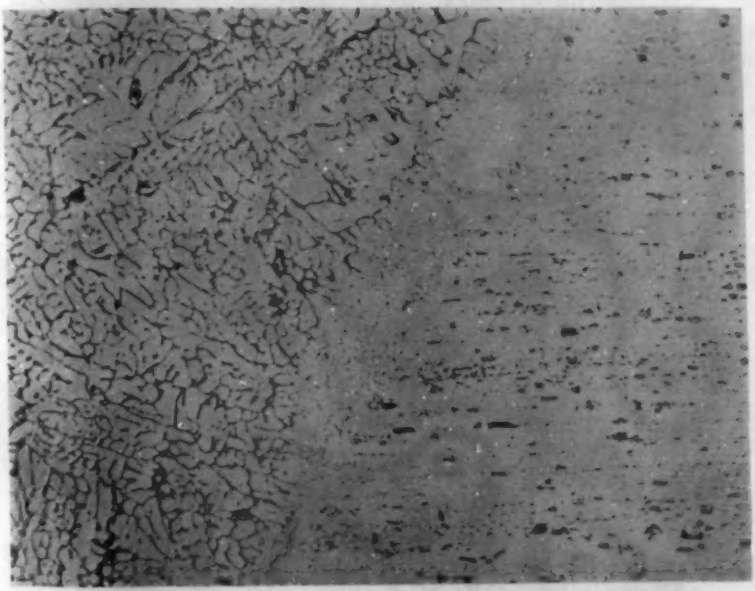

FIG. 1—THIS PHOTOMICROGRAPH SHOWS THE TRANSITION ZONE OF THE WELD SHOWN IN THE CROSS-SECTION VIEW. THE CAST STRUCTURE OF THE WELD PROPER IS SHOWN ON THE LEFT, THE TRANSITION ZONE IN THE CENTER, AND THE WROUGHT STRUCTURE OF THE BASE METAL ON THE RIGHT

The machine used in the experimental work was a portable welder of the variable voltage type. It has a current rating of from 50 to 300 amp. with a striking voltage of 50 to 60 volts. The machine was driven by an induction motor and was of two-bearing construction—motor rotor and generator armature on a common shaft.

Electrodes Suited for the Process

Experience in torch welding has shown that only two types of wire are required in welding sheet aluminum. For work on 2S or 3S, a pure aluminum (2S) wire is used, while when welding the strong alloys (17S, 25S, 51S) it is advisable to use a 5 per cent silicon, 95 per cent aluminum wire, especially when the work is not free to contract on cooling.

The strong alloys are all somewhat "hot short" and all have a high coefficient of expansion. Furthermore, they all melt at temperatures less than that of 2S. Therefore, if a 2S electrode is used, the added metal in the weld will solidify before the metal of the sheet. This places the contraction strains in the alloy sheet at a time when that metal, because of

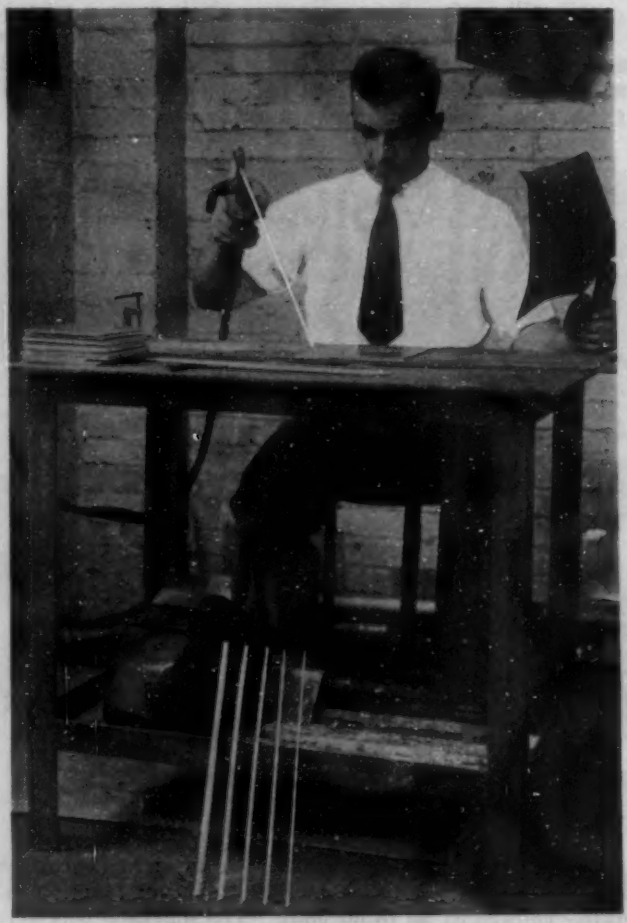

FIG. 2—THE PROPER ANGLE AT WHICH TO HOLD THE ELECTRODE. NOTE THE SERIES OF FLUX COATED ELECTRODES IN THE FOREGROUND

its high temperature is quite weak. This is likely to cause the formation of cracks adjacent to the weld, especially if the metal is clamped in a jig.

When the 5 per cent silicon electrode is used this cracking is eliminated. This alloy melts at a temperature slightly below the strong alloys and is noted for its hot strength and slight solidification contraction. Because of these characteristics, the added metal in the weld acts similarly to the

gate in a casting. This action places the contraction stresses in the weld metal where the hot strength is sufficient to prevent cracks.

It is often suggested that a filler rod (electrode) of the same composition as the sheet be used in welding strong alloys and castings. When welding castings this procedure will often be found satisfactory, or even advisable, but the 5 per cent silicon electrode will prove the most useful for welding the wrought strong alloys.

The electrodes are of the flux-coated type. In fact, the whole secret of successfully arc welding aluminum and its alloys depends upon the use of a proper flux. It has been found that a ⅛ in. diameter electrode will prove satisfactory for practically all gages up to ¼ in., provided that the operator varies his technique to suit the thickness of the metal. Since the flux coating is an insulator, it is necessary to limit the electrode length to such that when it is gripped at one end by the electrode holder, it will not be unwieldy. Experience has shown that an electrode about 15 in. long and coated to within 1 in. to 1½ in. of one end is quite satisfactory.

A Good Flux Must Be Used

The torch welding of aluminum was never a real success until a suitable and satisfactory flux was developed. Now that the flux method of welding this metal has become standard practice with the artificers, the torch welding of aluminum has reached a state of perfection. Just as a proper flux is essential for successful torch welding, so it is for arc welding. The experimental work quickly showed that a bare electrode would not prove satisfactory for arc welding aluminum, so investigations were begun to develop a satisfactory flux. This flux must serve the same purpose in arc welding that it does in torch welding. In addition, it must decrease the surface tension of the aluminum so that the molten metal will flow smoothly from the end of the electrode without the formation of drops; the flux should also aid in stabilizing the arc. In order to fulfill the above requirements, the flux should have the following characteristics:

1. It must melt at a temperature just below that of aluminum.

2. When molten, it must have the ability to remove aluminum oxide and do it very quickly.

3. The molten flux, containing the oxide must have a specific gravity less than that of the molten aluminum, and the difference must be enough that the flux will quickly and rapidly come to the surface of the molten metal, thus removing the oxide. This is particularly important in arc welding as the weld metal solidifies very rapidly.

4. The flux must be stable under the temperatures employed. For arc welding, this stability is of greater importance than for torch welding.

5. It must not deteriorate with time, nor must it be too deliquescent.

6. When dried on the electrode the flux must bind together well.

7. The molten flux must lower the surface tension of the molten aluminum so as to prevent the formation of drops on the end of the electrode as it melts.

A flux meeting the above requirements was finally developed by the author and is now being sold by the Aluminum Company of America, under the trade name of No. 25 Arc Welding Flux.

For coating the electrodes the flux is mixed with water to the consistency of thick paint and the wires are dipped in this paste. The excess flux is allowed to drain off and the rods are then dried. The flux coating on the metallic arc welding electrodes should be approximately 0.025 to 0.030 in. thick. To secure this thickness, it has been found advisable to dip the rods two times, thoroughly drying the first coating before the second one is applied. After a little experience the man coating the rods can judge the proper flux consistency to use, so that dipping twice will produce the desired flux thickness.

The dipping tube or trough should be made from aluminum or brass. Iron should be avoided, as the chemical action of the flux on that metal will cause contamination.

The rods should be dried in a current of warm air (about 60 deg. C.), or in a ventilated drying oven at about 65 deg. C. The drying will, of course, be rather slow at these temperatures, but if a higher drying temperature is used, the steam formed will cause the flux to crack and peel off.

Proper Characteristics of the Arc

The exceedingly high temperature of the arc, together with the short flame, is an important factor in developing the improved physical properties of arc welds as compared with torch welds. The high temperature produces rapid fusion in the work and the electrode, while the short arc localizes the heat. These properties greatly reduce the width of the heat affected area in the sheet, with a corresponding increase in weld efficiency. These same factors, combined with the rapid heat fluctuations, operate to the disadvantage of the process, since they set the lower limit in the range of work.

The metallic arc, furthermore, is almost inherently unstable for several reasons. One reason is that the filler metal must pass through the arc during the welding operation. Then, too, the normal tendency of the arc is to "pull off" a cold spot in preference to a hot one, and this leads to an unstable condition.

The flux coating on the rods is the primary stabilizing agent of the process. This flux must serve three important functions. It should furnish an insulating sheath around the arc, produce arc vapor with good conductivity, and reduce the surface tension of the molten electrode metal so that it will pass through the arc in small globules rather than in large drops.

A further aid in stabilizing the arc is the use of a short arc-length. This is entirely a mechanical factor, but in the experimental work the flux coating on the rods was designed to offer some aid. This was done by making the coating such that it did not melt as rapidly as the rod. That action produces a sheath of such length at the end of the rod that the operator can have the end of this sheath in contact with the work and, at the same time, have a satisfactory arc length.

As the currents used in arc-welding aluminum usually fall in the lower range of the smallest available welding generators, it will usually be found that the machine does not hold a stable arc. To correct this difficulty, a stabilizer consisting of about a half ohm resistance can be connected in series with the arc.

In welding aluminum with the metallic arc, only one polarity is required, regardless of the alloy being welded or the thickness of the work. This polarity is with the electrode positive and the work negative, or what is commonly called "reversed polarity."

The primary reason for using this polarity is to improve the arc stability. It does this by permitting the use of higher currents (since the

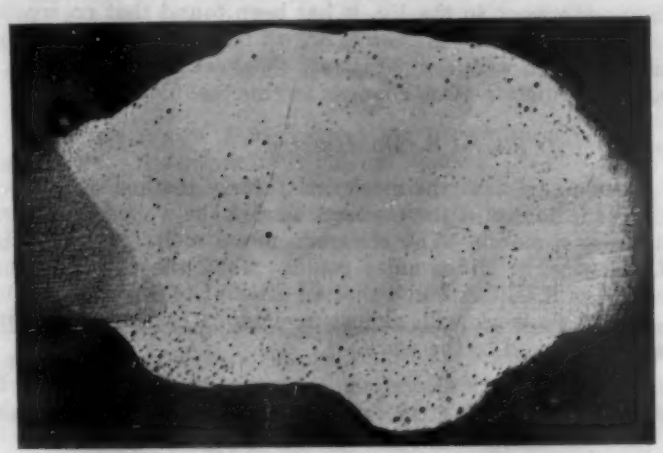

FIG. 3—CROSS-SECTION OF THE WELD MADE IN THE 7/32-IN. ALUMINUM PLATE SPECIMEN ILLUSTRATED

major portion of the heat is at the positive terminal), which, in turn, permit a heavier flux coating. Furthermore, the increase in current, in itself, improves stability.

Preparation of the Sheets

Preparation of the edges is not required on sheets up to ⅛ in. thickness, as the metallic arc will produce complete penetration when the edges are merely butted together. Material thicker than ⅛ in. however, should have the edges beveled to form a 90 deg. vee. This vee should not extend completely through the plate, but about an eighth-inch lip should remain. This lip may be notched with a chisel as in torch welding, but that is not necessary. If it is done, the notches should be about 1/16 in. to ⅛ in. deep and about ¼ in. apart.

Properly Designed Jigs Should Be Used

It is advisable to have some type of jig to hold the work in line when doing metallic arc welding. The jig, however, need not be as rigid as one used for torch welding, as less buckling accompanies metallic arc welding.

In all work where it is possible, the seam should be backed up with a copper or iron backing strip—preferably the former. This is advisable because the metal in the "puddle" is quite fluid and, unless some support is given, the action of the arc will blow holes in the weld, or penetration will be excessive. If the backing strip is flat on its entire surface, however, the under side of the weld will be found to be slightly concave, because of contraction on cooling. To avoid this trouble, the backing strip should be made with a slight clearance directly under the seam. Cutting a shallow groove in the backing plate, or, in the case of an angle used to back up a corner weld, grinding off the edge, will produce the desired clearance. Almost any suitable type of clamp or weight can be used to hold the work in place during welding.

In placing the work in the jig, it has been found that no spacing is required. Of course this conclusion is drawn from experimental work and is based on experience with comparatively short seams. Production work on long seams may dictate some changes in this technique.

How the Electrode Should Be Manipulated

It has been found that the most satisfactory method of "striking" the arc is to brush the end of the electrode across the work in a manner similar to lighting a match. The electrode metal melts very rapidly in the arc and, likewise, solidifies quite rapidly when the arc is extinguished. For this reason, it will be found that an attempt to draw the arc by touching the rod to the work will, almost invariably, result in "burning fast" or "freezing" the rod to the work.

The arc may be struck directly on the seam or on the jig near the edge of the work. It should be struck near the point where welding is to start, so that progress along the seam can be immediately begun. If much movement of the electrode is required after the arc has been first struck, it may "blow out." Quite often this results in the formation of a fused-flux coating over the end of the rod which interferes with re-establishing the arc.

Movement along the seam may be in either a forward or backward direction, as the operator desires or the work dictates. The movement, however, should be at a uniform rate so that an even bead is made. To secure the best results, the electrode should be held approximately vertical at all times. It has been found, however, that slanting the electrode slightly (not over 20 deg. from the vertical) will sometimes prove satisfactory, and will be more convenient to the operator. If this is done, the electrode should point away from the direction of motion.

The arc should always be kept as short as possible, in order to improve its stability. An arc length of ⅛ in. to 3/16 in. is the most satisfactory, and it should never exceed ¼ in. When a long arc is used, the arc "waves" excessively, small globules of semi-molten metal are thrown about, and the arc is hard to maintain. Proper thickness of the flux coating on the electrodes is a great aid in maintaining a uniform arc length. When the electrodes are coated as previously described, it will be found that the flux coating will melt a little more slowly than the metal in the rod. This

action produces a flux sheath around the arc which, in addition to stabilizing the arc and limiting its "play," serves as a guide for arc length.

A detailed description of arc manipulation is practically impossible, for, as anyone familiar with arc welding knows, much of the technique depends on the operator's "feel." After a little practice, the operator will find that the arc welding of aluminum is a very simple process. There is no weaving of the electrode as in steel welding. The electrode is advanced in a straight line along the seam. In the case of heavy plate, the electrode is moved forward and backward to build up a bead of the desired height; the electrode is never moved back and forth across the weld.

The most practical use of the metallic arc for aluminum welding is in making a straight butt weld or a corner weld. For these applications, the method has been found quite satisfactory for all of the aluminum alloys. The use of the metallic arc for tee and lap welds has not been very extensively investigated, but what work has been done indicates fair results.

The metallic arc can be used for welding aluminum sheet No. 14 B.S. gage and heavier. An upper limit has not been set, as this limit depends more upon the results desired than on the possibilities of the process. The heaviest material used experimentally was $\frac{3}{8}$-in. sheet, and the welds were very satisfactory.

Why the Arc Will Burn Through Thin Gage Sheets

The lower limit can rather definitely be placed at No. 14 gage as it has been found that lighter material will burn through with the minimum current that can be used. This trouble appears to be an inherent characteristic of the metallic arc. It is chiefly due to the fact that the minimum current which will maintain a stable arc is rather high.

The theory has been advanced by J. B. Green of the Fusion Welding Corporation that the variation of the heat, caused by metal passing from the electrode to the work, is the cause of the trouble. This theory is: As the metal drop which has been formed on the end of the electrode passes to the work and momentarily extinguishes the arc, the heat is varied from maximum to zero. As the arch is re-established after the passage of the drop, the heat again rises to the maximum. It is suggested that this great heat variation is the factor which makes the use of the metallic arc on light sheet impossible.

A Few Difficulties Which Beset the Operator

There are only a few difficulties that the operator will encounter when arc welding aluminum, and most of these can be attributed to technique. One difficulty which is peculiar to this process is the formation of the insulating, fused-flux coating over the tip of the electrode when the arc "blows out." This characteristic is rather annoying and is a source of time loss, but otherwise is not very important. To re-establish the arc, it is necessary to tap the end of the electrode on the work until the coating cracks off, or to clip the end of the rod off with a pair of pliers.

Moving along the seam too slowly results in burning holes or in de-

veloping an excessive bead, while moving too rapidly results in poor penetration. Using too high a current will result in "burned" work, and too low a current results in little or no penetration.

The most outstanding advantage in the use of metallic arc welding is in its cheapness; the operating speed of this method is greater than for any other fusion welding process. Where applicable, the arc welding process is cheaper than the oxy-hydrogen or oxy-acetylene welding process. This saving is in the difference in the cost of gas as compared with the cost for electrical power and in the difference in labor cost. The first cost of the arc welding process will probably be greater, especially for small installations, while the cost of electrodes will be somewhat more than for filler wire and flux in torch welding. The decreased operating costs, however, will soon show a saving.

The metallic arc welding process is particularly applicable to certain classes of work such as the reclamation of defective castings in foundries, repairing broken castings, architectural shapes, etc. There is less buckling and warping of the work when arc welding than when torch welding, and preheating before welding can be largely eliminated. The temper of the sheet is less affected during arc welding than during torch welding, as in the former case the heat is much more concentrated and localized and the weld is made much more quickly.

The flux used in arc welding, like that for torch welding, is corrosive and must be removed after welding is completed. The most satisfactory method to remove this flux is to soak the weld in hot 5 per cent nitric acid or warm 10 per cent sulphuric acid solution for a short time and then to rinse it in hot water. Soaking in hot water, at the same time scrubbing the weld with a stiff brush, is also quite satisfactory. The weld may be cleaned by impinging a steam jet on it. This method has advantages for removing the flux from corners.

After the flux has been removed, the weld can be finished by chipping off the excess metal with a pneumatic chisel and then hammering the weld with an automatic hammer. Care should be taken that the hammering does not start small cracks that will reduce the strength. Another method of finishing is to grind off the excess weld metal and then polish the work on a buffing wheel. This method is to be preferred where a good finish is desired. A good weld finished in this manner cannot usually be detected.

Physical Properties of Electrically Welded Steel Tubing*

By H. L. Whittemore,[1] J. S. Adelson,† and E. O. Seaquist[1]

I. INTRODUCTION

For many of our industrial processes tubes and pipes are used to convey liquids and gases. They are used in large quantities for the distribution of water and gas in our cities, and for pipe lines across the country to bring oil and gas to manufacturing and shipping centers. Tubing is used in many industrial applications where high pressures are applied externally as well as internally. In department stores tubing is used for pneumatic-conveyor systems and in factories for the rollers in roller conveyors. It is used for conduit for electric wiring. In automobiles it is used for driving shafts, steering columns, water manifolds, and exhaust pipes.

From a theoretical standpoint there are, in many cases, advantages in using tubes as structural members and as parts of machines instead of using other cross sections. In the past, however, the high cost of tubing has limited its use, frequently making it more economical to use rolled sections having greater weight.

If the member is subjected to tensile stresses only, the cross-sectional area and, therefore, the weight are the same whether it is solid or tubular. For some conditions the tubular member is to be preferred because it is less likely to vibrate.

If the member is subjected to compressive stresses, as in a strut or column, a tubular member is efficient because for a given cross-sectional area the moment of inertia of a circular tube is the same about all centroidal axes, and it is relatively high.

When long columns fabricated from rolled shapes fail, they often fail by twisting if the torsional rigidity is low. Tubular columns, which have a relatively higher torsional rigidity than any other commercial form, probably never fail by twisting.

If the member is subjected to transverse loads, as in a beam, a comparison of the strengths of tubular and other sections can only be made after the section moduli have been computed. In general, higher section moduli and moments of inertia can be realized practically with tubes than with rolled sections except when a large difference is desired in two different planes, as in a narrow I beam.

When subjected to twisting couples, as in shafts for the transmission

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of power, a tube is stronger for the same weight than a solid cylindrical shaft or other cross section.

If the member in service is accidentally subjected to unexpected local forces, tubes will in many cases prove more satisfactory than structural shapes, because tubes have no unsupported flanges to be damaged.

Steel tubing is used almost exclusively to form the fuselage structures of airplanes. This is an example of a structure designed to obtain the greatest strength for a given weight.

In the past it has been difficult and expensive to join tubular members of a structure by rivets or fittings, but during the past few years fusion welding has come into extensive use for fabricating structures and machines.

It is believed that tubes can be welded more satisfactorily than rolled shapes because the wall of the tube is somewhat thinner, the thickness is more nearly the same for all members, and the surface of tubes is convex.[2]

In the past, tubing of the desired material and dimensions has not always been available commercially, or if available, the price has been prohibitive. As the cost of tubing decreases, due to improvements in the method of manufacture, the use of tubes for the members of small machines and light structures should increase.

That structures fabricated from tubes having welded longitudinal seams possess the advantages which have been outlined is shown by tests recently made in Germany[3] of towers for electrical transmission lines.

These specimens consisted of four vertical members connected by diagonal lattices. Some were fabricated from steel tubes having welded longitudinal seams, the connections being made by oxyacetylene welding. Other specimens of the same dimensions were fabricated from rolled angles, the connections being made by riveting.

The specimens were 6 m (19.68 feet) and 12 m (39.37 feet) high. The base was anchored to a foundation and the horizontal force at the top increased until the tower failed.

The efficiency of the towers at maximum load computed on the weight of the towers was, for the 6 m towers, angle-iron tower 1, tubular tower 2.07, and for the 12 m towers, angle-iron tower 1, tubular tower 1.66.

The report concludes that thin tubes having a welded longitudinal seam, which is comparatively cheap, can be used successfully instead of rolled sections.

Tubular towers are especially desirable if freight rates are high or if the pressure on the soil must be low.

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[2] "Strength of Welded Joints in Tubular Members for Aircraft" will be published at an early date as a Technical Note of the National Advisory Committee for Aeronautics, Washington, D. C.

[3] A. Hilpert and O. Bondy, Berlin-Charlottenburg. Zeitschrift des Vereines Deutscher Ingenieure, 73, No. 24, p. 805; June 15, 1929.

Tubular towers offer less wind resistance and have a better appearance than towers fabricated from rolled sections or reinforced concrete.

II. PURPOSE OF THE INVESTIGATION

Tubes made from sheet or strip steel, with the longitudinal seam electrically welded, are being used commercially. As there is little information on the strength and other properties of these tubes, the Bureau of Standards, in cooperation with Steel & Tubes (Inc.), has made the present investigation to determine the physical properties of electrically welded tubing. It is hoped that the investigation will enable designers of structures and machines to use welded tubes economically under tensile loads and under compressive loads on short lengths, as in aircraft; under torsional load, as in steering columns and drive shafts of automobiles; under internal pressure, as in pumps and jacks; and for flanged connection, as in exhaust pipes for gasoline engines. Tests have been made to determine (1) variations in diameter and in thickness of wall; (2) the modulus of elasticity, proportional limit, yield point, tensile strength, and elongation of full section; (3) the axial crushing strength; (4) the torsional modulus of elasticity, and torque at elastic limit and ultimate torque; (5) the bursting strength under hydrostatic pressure; (6) the tensile strength of the weld; (7) the hardness (Rockwell number); (8) the suitability for flanging; and (9) the microscopic structure of the weld.

The results obtained from the axial crushing tests, the bursting tests, the tensile tests of the weld, and the flanging tests depended greatly upon the strength and ductility of the welds.

III. ACKNOWLEDGMENTS

Steel & Tubes (Inc.) cooperated in this investigation by furnishing all the tubing and assisting in the tests.

The chemical analyses were made by R. M. Fowler, of the chemistry division. The microscopic examinations were made by C. E. Eggenschwiler, of the metallurgical division.

IV. DESCRIPTION OF TUBING

1. Material

Typical chemical analyses, shown in Table 1, indicate that most of these tubes are mild steel containing about 0.08 per cent carbon. This tubing is also made in higher carbon steels, such as S. A. E. 1025, examples of which are tubes Nos. 85 and 86.

The manufacturer states that all tubes were made from box-annealed cold-rolled strip steel with the exception of some of the heavier gage tubes which were made from pickled hot-rolled strip steel, examples of which are tubes Nos. 58, 84, and 85.

The sizes, thicknesses of wall, and types of treatment of all the tubes are shown in Table 2.

2. Method of Manufacture

Strip steel of the required width is passed through a series of rolls to give it the tubular form.

TABLE 1.—*Chemical analysis*

Tube No.	Carbon	Manganese	Phosphorus	Sulphur	Silicon
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*
7	0.08	0.33	0.010	0.030	<0.01
10	.09	.43	.010	.030	<.01
13	.08	.43	.010	.030	<.01
26	.06	.36	.010	.030	<.01
31	.05	.33	.015	.025	<.01
49	.05	.37	.010	.025	<.01
58	.05	.33	.010	.020	<.01
59	.05	.40	.015	.035	<.01
63	.06	.37	.010	.025	<.01
91	.05	.31	.010	.020	<.01
46	.04	.36	.015	.050	<.01
71	.07	.34	.010	.030	<.01
85	.23	.47	.020	.030	<.02
40	.00	.41	.025	.053	<.01
41	.11	.41	.026	.052	<.01
56	.00	.38	.013	.040	<.01
67	.07	.40	.016	.050	<.01
84	.07	.36	.010	.023	<.01
86	.25	.42	.011	.022	<.01
98	.05	.37	.013	.030	<.01
104	.11	.44	.014	.045	<.01
107	.08	.40	.020	.044	<.01

TABLE 2.—*Results from tensile, hardness, and axial crushing tests*

Tube No.	Type of treatment	Nominal size		Wall thickness		Tensile test of full section				Rockwell number, 1/16-inch ball, 100-kg load	Axial crushing test (ultimate strength)
		Outside diameter	Wall thickness	Minimum	Maximum	Yield point	Ultimate strength	Elongation—			
								In 8 inches	In 2 inches		
		Inch	*Inch*	*Inch*	*Inch*	*Lbs./in.²*	*Lbs./in.²*	*Per cent*	*Per cent*		*Lbs./in.²*
17	A	1/8	0.028	0.027	0.028	39,800	52,200	25.0	39.8		
18	B	1/8	.028	.028	.030	49,000	57,100	16.7	32.0		
19	C	1/8	.028	.029	.030	36,600	52,700	30.0	42.5		
7	A	1/8	.032	.030	.031	53,050	58,450	9.6	19.7	66.6	
8	B	1/8	.032	.030	.031	55,400	57,700	6.2	15.0	71.2	
9	C	1/8	.032	.030	.031	35,150	48,950	27.1	42.0	59.0	
14	A	1/8	.035	.034	.036	46,700	52,050	9.5	24.2	65.3	
15	B	1/8	.035	.034	.035	53,000	56,200	5.9	17.0	72.8	
16	C	1/8	.035	.035	.036	33,100	49,400	27.7	40.7	59.2	
66	A	1/8	.049	.045	.047	56,650	61,000	9.4	22.5	78.6	
67	B	1/8	.049	.048	.050	58,000	62,100	7.5	19.0	78.5	
68	C	1/8	.049	.047	.049	39,550	50,400	25.9	38.5	65.2	
40	A	1/8	.035	.035	.038	57,050	62,200	10.0	25.0	71.0	
41	B	1/8	.035	.035	.036	63,200	66,850	7.8	21.0	71.2	
42	C	1/8	.035	.036	.039	37,950	54,000	32.0	48.0	59.0	
4	A	7/64	.042	.041	.043	47,750	51,100	11.8	31.5	65.6	
5	B	7/64	.042	.041	.043	56,850	58,000	7.3	22.2	79.4	
6	C	7/64	.042	.039	.041	35,200	49,650	33.7	48.7	50.2	
37	A	1/8	.049	.051	.054	49,200	53,400	12.2	32.5	65.8	
38	B	1/8	.049	.049	.050	51,400	55,150	9.7	26.5	75.1	
39	C	7/64	.049	.052	.054	34,500	49,750	31.9	47.5	57.1	
34	A	1	.028	.027	.028	47,150	55,600	15.0	27.5	59.2	56,400
35	B	1	.028	.028	.029	51,050	57,150	8.6	21.0	64.5	58,450
36	C	1	.028	.027	.029	38,350	56,750	33.0	44.0	51.8	42,200
43	D	1	.028	.030	.030	53,650	58,250	8.5	20.5	64.0	55,750
63	A	1	.035	.033	.035	43,300	51,100	19.2	27.0	60.8	52,400
64	B	1	.035	.034	.035	48,800	55,000	8.5	18.5	55.4	55,650
65	C	1	.035	.035	.036	35,600	48,800	30.7	44.0	41.5	43,500
97	A	1	.035	.031	.032	54,850	57,450	9.5	26.0	67.6	56,250
98	B	1	.035	.031	.033	61,450	62,200	6.2	15.5	75.8	65,800

TABLE 2.—*Results from tensile, hardness, and axial crushing tests*—Continued

Tube No.	Type of treatment	Nominal size: Outside diameter	Nominal size: Wall thickness	Wall thickness: Minimum	Wall thickness: Maximum	Tensile test of full section: Yield point	Tensile test of full section: Ultimate strength	Tensile test of full section: Elongation—In 8 inches	Tensile test of full section: Elongation—In 2 inches	Rockwell number, 1/16-inch ball, 100-kg load	Axial crushing test (ultimate strength)
		Inches	*Inch*	*Inch*	*Inch*	*Lbs./in.²*	*Lbs./in.²*	*Per cent*	*Per cent*		*Lbs./in.²*
76	E	1	0.035	0.034	0.034	48,950	54,800	13.1	33.0	66.0	55,700
77	B	1	.035	.034	.035	54,300	58,050	8.7	25.5	71.7	58,300
78	C	1	.035	.035	.037	41,100	51,150	31.3	49.0	56.0	47,100
44	D	1	.035	.035	.036	48,050	52,490	15.6	33.0	59.2	54,450
31	A	1	.049	.048	.049	49,100	55,250	12.5	30.0	66.4	59,100
32	B	1	.049	.049	.051	56,350	59,600	8.2	22.5	72.7	63,450
33	C	1	.049	.049	.050	33,950	51,950	25.0	38.5	56.2	53,500
108	D	1	.049	.049	.050	50,300	56,800	10.6	28.0	74.6	59,600
28	A	1	.065	.064	.067	50,100	53,600	12.8	32.5	70.4	60,750
29	B	1	.065	.064	.065	50,150	53,150	10.9	30.0	66.2	60,350
30	C	1	.065	.064	.066	34,900	48,250	33.9	51.5	51.0	54,000
93	A	1	.065	.064	.065	51,050	55,950	11.2	31.0	71.3	60,450
92	B	1	.065	.065	.066	61,100	63,100	7.0	20.0	79.3	66,600
109	D	1	.065	.063	.064	46,700	49,000	14.0	25.0	67.2	54,950
73	E	1	.083	.079	.081	56,000	61,050	10.5	26.0	75.0	68,550
74	B	1	.083	.081	.083	49,550	59,450	15.2	33.0	77.2	[1] 70,350
75	C	1	.083	.080	.081	37,150	51,550	29.7	48.5	58.2	[1] 62,450
25	A	1¼	.049	.047	.049	50,200	54,250	14.2	36.0	71.9	55,750
26	B	1¼	.049	.047	.049	53,750	56,850	9.7	27.5	77.6	59,350
27	C	1¼	.049	.047	.049	39,600	52,600	31.9	54.0	56.6	47,200
1	A	1½	.035	.034	.035	42,950	48,500	25.5	43.0	63.9	46,900
2	B	1½	.035	.034	.035	48,050	50,350	17.3	31.5	68.2	52,100
3	C	1½	.035	.034	.035	37,400	53,350	27.6	45.8	64.9	39,700
13	A	1½	.065	.063	.064	43,000	49,350	23.6	49.5	63.1	52,400
20	B	1½	.065	.064	.065	47,750	50,450	21.5	44.0	73.0	[2] 52,550
21	C	1½	.065	.065	.066	35,650	52,400	37.2	59.5	46.1	48,200
84	B	1¾	.120	.123	.124	55,350	58,650	13.8	38.5	78.8	[1] 64,800
10	A	2	.035	.035	.036	48,350	54,090	19.4	42.0	66.8	48,150
11	B	2	.035	.035	.035	52,800	54,850	12.6	29.7	67.5	50,950
11a	B	2	.035	.036	.037	54,050	58,550	13.4	32.5	72.2	53,050
12	C	2	.035	.035	.037	36,700	52,900	34.8	57.0	52.9	39,750
12a	C	2	.035	.034	.036	36,650	50,150	33.5	57.0	56.3	40,400
69	E	2	.035	.033	.034	34,150	44,900	32.1	53.0	46.4	35,650
47	D	2	.035	.034	.036	52,450	56,300	11.9	31.0	76.4	49,650
91	A	2	.049	.050	.052	44,400	50,150	18.4	45.5	66.9	47,500
90	B	2	.049	.051	.052	49,100	52,700	13.0	30.5	69.9	51,300
48	D	2	.049	.050	.050	54,850	59,450	12.5	33.0	72.5	55,750
71	E	2	.065	.062	.063	46,300	51,700	23.1	46.0	69.8	52,150
70	B	2	.065	.062	.063	47,900	53,700	16.1	40.5	70.0	53,500
72	C	2	.065	.061	.064	35,850	48,950	33.2	53.5	57.0	41,350
51	D	2	.065	.062	.063	49,950	55,700	13.1	37.0	69.5	55,050
49	H	2	.065	.066	.067	67,200	68,650	3.1	9.5	83.9	69,700
107	H	2	.065	.065	.066	74,350	78,250	2.5	7.0	88.6	[2] 79,050
50	D	2	.083	.080	.081	45,700	50,050	18.8	48.0	64.2	[3] 51,800
106	D	2	.083	.081	.082	57,150	58,850	12.4	38.0	79.6	60,250
22	A	2¼	.049	.048	.049	45,600	47,300	30.0	52.7	57.8	44,250
23	B	2¼	.049	.047	.049	47,250	48,600	27.2	44.5	59.5	47,100
24	C	2¼	.049	.049	.050	32,100	47,550	31.2	60.5	47.2	39,800
58	D	2¼	.035	.034	.035	54,850	56,850	12.2	35.0	74.3	51,450
57	D	2½	.065	.060	.062	55,200	58,450	13.4	40.0	79.0	55,100
104	H	2½	.065	.060	.062	70,850	75,850	2.5	7.0	87.1	[2] 73,100
56	D	2½	.083	.080	.081	57,700	62,800	14.9	37.0	85.0	62,050
59	D	2½	.083	.080	.082	53,100	58,800	22.6	44.5	82.2	96,500
105	D	2¾	.083	.079	.081	57,500	64,150	13.1	19.0	81.6	61,600
85	B	2½	.095	.097	.097	63,500	72,450	15.7	42.0	85.9	68,400
86	D	2¾	.083	.083	.085	60,850	66,300	18.6	34.5	83.5	61,700
62	D	3	.042	.041	.042	47,850	55,050	17.9	35.5	78.0	43,100
61	D	3	.065	.061	.062	45,050	54,550	21.9	46.0	74.8	47,700
102	D	3	.065	.063	.064	52,350	57,600	23.5	52.0	77.2	51,100
60	D	3	.083	.079	.081	51,900	59,900	15.8	37.5	82.7	55,500
103	D	3	.083	.080	.082	48,950	56,100	19.9	45.5	77.0	51,000

[1] Slight crack in weld at outer edges of folds.
[2] Crinkled locally at top and bottom on opposite sides, but did not fold.
[3] Deep crack in weld at outer edges of folds.

TABLE 2 (Continued)

Results from Tensile, Hardness and Axial Crushing Tests

Symbol	Type of Treatment	Symbol	Type of Treatment
A	As-welded	D	Rolled
B	Swaged	E	Cut-burr
C	Swaged-annealed	H	Hard-rolled

The edges along the longitudinal seam are accurately butted as the blank is propelled under two electrodes which make continuous contact on both sides of the seam. The electrical resistance of the metal brings the abutting edges to the welding temperature. Forces are immediately applied by mechanical fixtures to complete the weld. The tubing is said to be welded at a speed of about 50 feet per minute.

(a) TYPES OF TREATMENT

Figures 1 and 2 show the typical cross sections and welds of some of the tubes.

(1) *As-welded.*—This tubing is in the condition in which it comes from the welding machine. It has a small burr on the inside and outside of the weld. This diameter is from 0.02 to 0.04 inch greater than the nominal outside diameter.

(2) *Cut-burr.*—This tubing is similar to the as-welded tubing except that the outside burr has been removed by a planer tool as it leaves the welding machine.

(3) *Swaged.*—The as-welded tubing is passed through a swaging machine which reduces its outside diameter to the nominal size and removes the burr on both sides. The machine has a pair of dies, each of which has a slightly tapered longitudinal semicylindrical groove. The opposite end of the dies from which the tube enters conforms to the desired outside diameter of the tube. A cylindrical mandrel, of a size corresponding to the desired inside diameter of the tube, is inserted and held stationary at a point between the dies. The dies revolve about the tube and at the same time hammer it to its nominal size while the tube is being pulled through the machine.

The as-welded tubing may also be swaged without the stationary mandrel on the inside, thus forming a tube of uniform thickness and outside diameter, but with a small burr on the inside at the weld.

The variations in thickness of wall and in outside diameter of swaged tubes are small.

(4) *Rolled.*—The as-welded tubing is passed through a series of rolls arranged in pairs, each roll having a semicircular groove. These rolls reduce the outside diameter to the nominal size and roll down the burr. A mandrel, in which small rolls are mounted and adjusted to conform to the desired inside diameter of the tube, is inserted and held stationary in the tube at a point between the outside rolls. The rolls in the mandrel roll down the inside burr.

The thickness of wall at the weld of the rolled tubes is somewhat greater for a width of 0.10 to 0.20 inch, the increase being from 2 to 20 per cent and averaging 8 per cent. Due to the rolling operation,

the outside diameter of the tubing is constant, but the inside diameter is least at the weld.

(5) *Hard rolled.*—The strip steel from which this tubing is made is cold worked to a greater extent than other rolled tubing, which increases its strength.

(6) *Annealed.*—The ductility of the tubing which has been cold worked in previous operations may be increased by annealing. Annealed tubing is used for parts which are greatly deformed in fabrication.

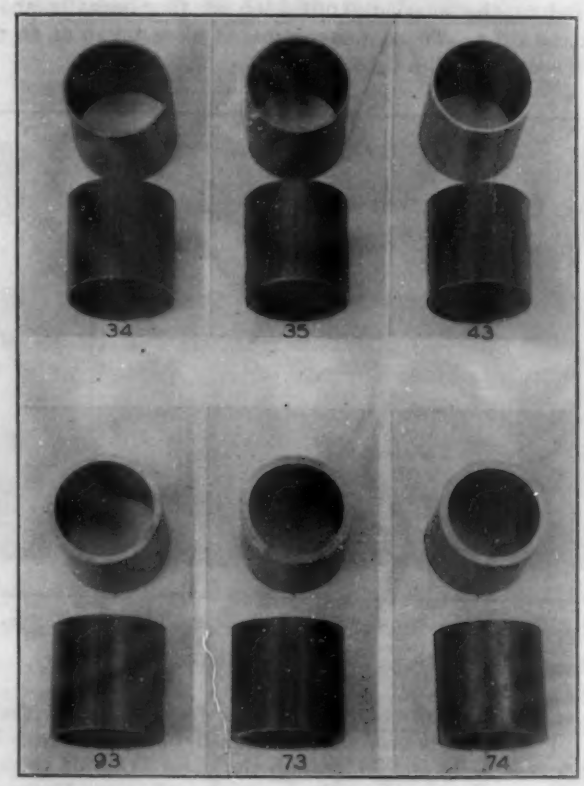


FIG. 1—CROSS SECTIONS AND WELDS OF SOME 1-INCH TUBES

Tube number	34	35	43
Type of treatment	As welded	Swaged	Rolled
Tube number	93	73	74
Type of treatment	As welded	Cut-burr	Swaged

The only annealed tubes that were included in this investigation were annealed after swaging.

V. METHODS OF TESTING AND RESULTS

To determine the difference in tensile strengths at the ends of some of the 15-foot lengths of tube, one tensile specimen was cut from each end of tubes Nos. 1 to 25, inclusive. The average difference between

the tensile strengths of the two specimens was 1.2 per cent and the maximum difference was 2.5 per cent. It was concluded, therefore, that the physical properties did not vary appreciably in the length of the tube. Only one tensile specimen was cut from each of the remaining tubes, which varied in length from 10 to 18 feet, and no sequence for cutting specimens from the remaining length was followed in the various tests.

1. Diameter and Thickness of Wall

The outside diameters of swaged, rolled, and swaged-annealed tubes were measured to the nearest 0.001 inch at four equally spaced diameters around the tube. These measurements were taken at an arbitrarily selected cross section of the tube.

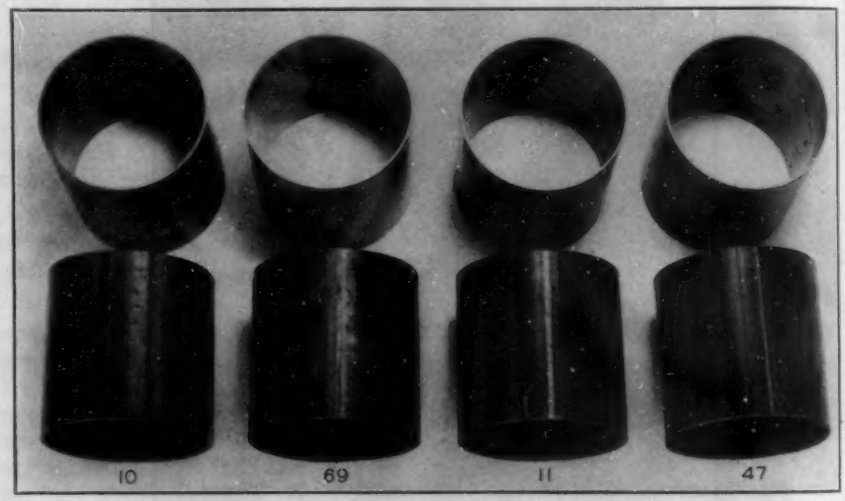


Fig. 2—Cross Sections and Welds of Some 2-Inch Tubes

Tube number	10	69	11	47
Type of treatment	As welded	Cut-burr	Swaged	Rolled

After the tube had been cut into lengths for specimens, the thickness at the ends of the specimens was measured to the nearest 0.001 inch on four elements equally spaced around the tube. One of these measurements was taken on the weld of the swaged and swaged-annealed tubes, but not on the weld of the as-welded, cut-burr, or rolled tubes. The thickness of the wall did not vary longitudinally more than 0.001 inch on any given element of the cylinder.

The maximum differences in outside diameters and wall thicknesses of the four measurements are shown in Figs. 3 and 4.

Fig. 3 shows the per cent of the 25-swaged, 23-rolled, and 20-swaged-annealed tubes having the maximum differences of outside diameters indicated.

Fig. 4 shows the per cent of the 91 tubes of all types of treatment having the maximum differences of wall thickness indicated.

2. Tensile Test of Full Section

One tensile specimen, 20 inches long, was cut from each length of tubing and then marked with a center punch at each inch along opposite elements of the cylinder for a distance of 10 inches. Mandrels which fitted the inside of the tube were inserted into each end of the specimen. These mandrels were slightly longer than the jaws of the testing machine, and their inner ends were rounded.

The testing machine had a capacity of 100,000 pounds. It was of the universal screw-power type and driven by an electric motor. The ends of the specimen were gripped between the V-shaped grooves of the jaws.

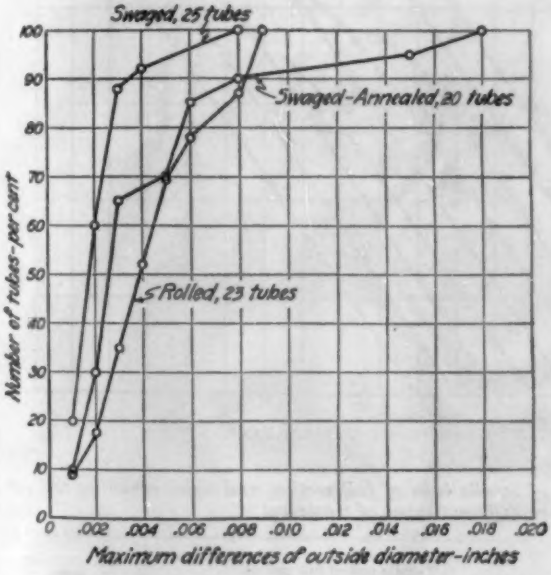


Fig. 3—Maximum Differences of Outside Diameter

To find the number of tubes which did not exceed a given tolerance, say 0.006 inch, find 0.006 on the horizontal scale, then determine where the ordinate cuts the curve for the tube of the desired treatment, say "swaged.". Read the number of tubes horizontally on the scale at the left. For this case, 96 per cent of the 25 "swaged" tubes did not exceed the tolerance.

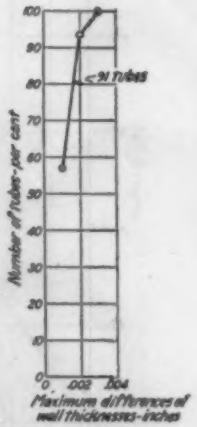


Fig. 4 — Maximum Differences of Wall Thickness

To find the number of tubes which did not exceed a given tolerance, say 0.002 inch, find 0.002 on the horizontal scale, then determine where the ordinate cuts the curve representing the tubes of all types of treatment. Read the number of tubes horizontally on the scale at the left. Then 93 per cent of the 91 tubes did not exceed the tolerance.

The yield point was determined by the drop of the beam and checked by dividers set on the specimen on an 8-inch gage length. The speed of the moving head of the machine was 0.11 inch per minute during this part of the test. The speed was then increased to the next higher speed of 0.44 inch per minute, which was maintained until the ultimate load and fracture were reached.

The elongation was determined by fitting the fractured ends together and measuring the distances between original 2 and 8 inch gage marks

on each side of the fracture. These marks were selected so as to have the fracture as near the center of this distance as possible.

The yield point, ultimate strength, and elongation for each tube are given in Table 2, and the average of these for the different types of treatment is given in Table 3.

The modulus of elasticity and proportional limit were obtained from a few specimens of the different types of treatment. One-inch tubes

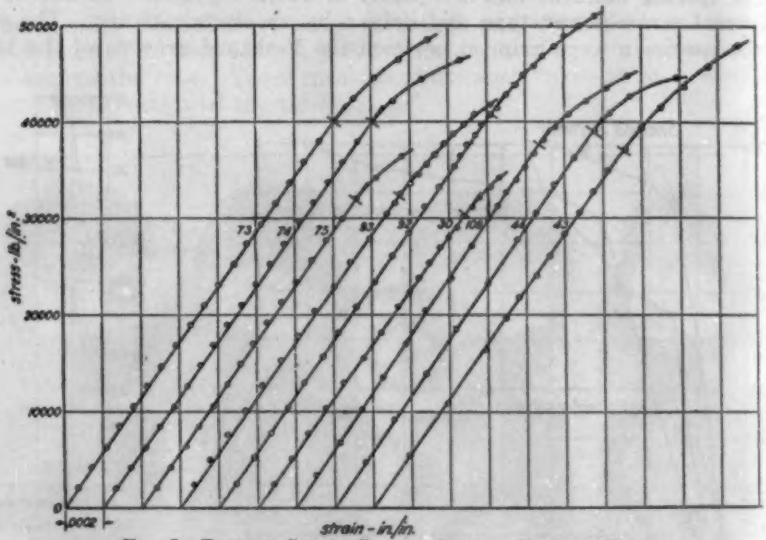


FIG. 5—TYPICAL STRESS-STRAIN CURVES, TENSILE TEST

TABLE 3.—*Average results of tensile tests of full section and axial crushing test for the different types of treatment*

Type of treatment	Tensile test of full section					Axial crushing test	
	Number of tubes tested	Yield point	Ultimate strength	Elongation—		Number of tubes tested	Ultimate strength
				In 8 inches	In 2 inches		
		Lbs./in.²	*Lbs./in.²*	*Per cent*	*Per cent*		*Lbs./in.²*
A	19	48,420	53,820	20.0	33.5	12	53,350
E	4	46,350	53,090	19.7	29.5	4	53,010
B	25	53,600	57,600	11.8	28.0	18	57,800
C	20	36,350	51,060	31.1	48.5	13	46,100
D	20	52,200	57,400	15.4	36.0	20	54,700
H	3	70,800	74,250	2.7	7.8	3	73,900

Symbol	Type of treatment	Symbol	Type of treatment
A	As-welded.	D	Rolled.
B	Swaged.	E	Cut-burr.
C	Swaged-annealed.	H	Hard-rolled.

were selected because they were available in a wide range of thicknesses. A Ewing extensometer was used on an 8-inch gage length. The deformation was measured to 0.0002 inch by the smallest division and estimated to 0.00002 inch.

The stress-strain curves for the nine specimens tested are shown in Fig. 5 and the numerical results are given in Table 4.

3. Axial Crushing Test

This test was made on all tubes of 1 to 3 inches outside diameter, inclusive.

The specimens, 2½ inches long, were cut from the tube in a lathe and loaded longitudinally in a testing machine. The moving head of the machine applied its force through a spherical bearing. The speed

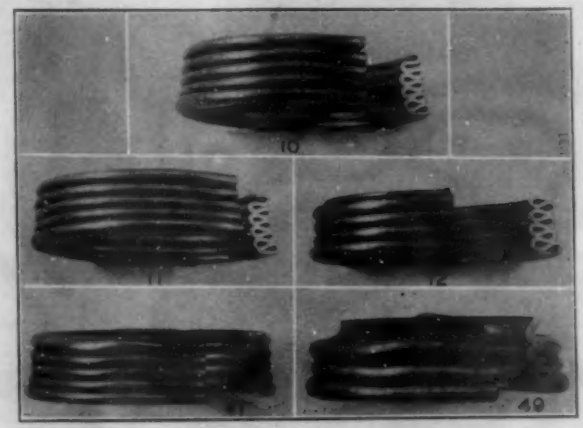


Fig. 6—Typical Crush Specimens

Tube number.....	10	11	12	47	49
Type of treatment....	As welded	Swaged	Swaged-annealed	Rolled	Hard rolled

of the moving head was 0.11 inch per minute, and as the ultimate load was reached the specimen started to crinkle. The speed was then increased to 0.44 inch per minute and the test completed by crushing the whole specimen into folds. The results are given in Table 2.

A few typical specimens are shown in Fig. 6. The weld is nearest the observer, and a segment is cut away to show a section of the folded metal.

4. Torsion Test

This test was made on swaged and rolled tubes of 1 to 3 inches outside diameter, inclusive. The total length of each specimen was 43 inches and the gage length was 30 inches. Mandrels which fitted the inside of the tube were inserted into each end of the specimen to prevent the tube from being crushed between the jaws of the torsion machine.

Fig. 7 shows the torsion machine with a specimen under test. Fig. 8 shows the twist-measuring instrument assembled on a specimen. With

specimen *A* in the torsion machine the ring *B*, supporting the pointers, and the ring *C*, supporting the arcs, are spaced and held perpendicular to the specimen by pressing them against the end faces of jig *D* when it is resting on the specimen on its V-shaped ends. The rings are made concentric with the tube by adjusting three radial screws, having square ends, set 120 deg. apart in the ring. Between the square-ended screws are sharp-pointed screws similarly spaced, which are screwed down against the tube so the ring cannot turn on the tube. The jig is then removed, and the balanced pointer *E* set into a semicircular groove at the end of the supporting arm and made secure by thumbscrew *F*. The small glass *G*, with a horizontal hairline, is attached to the end of the balanced

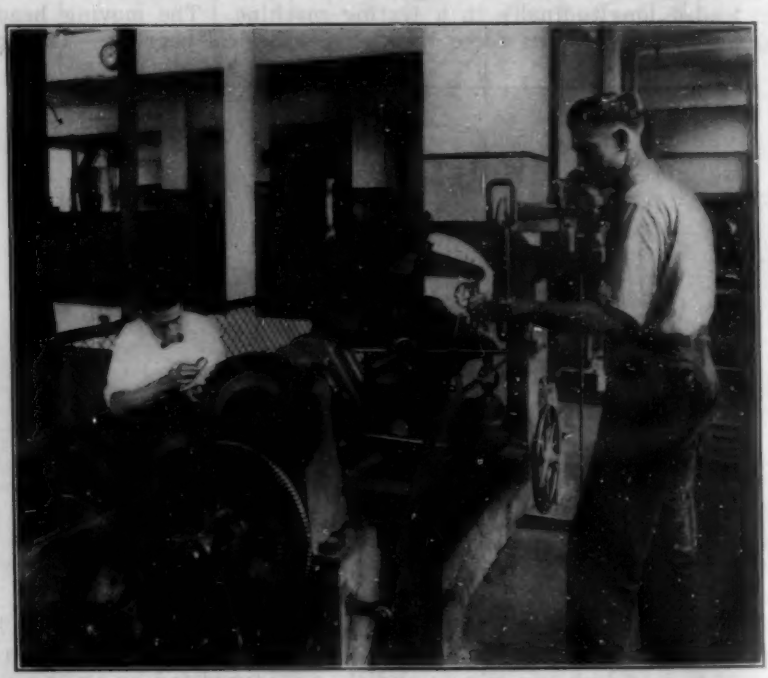


FIG. 7—TORSION MACHINE WITH A SPECIMEN UNDER TEST

pointer by means of a thin flat spring. The spring keeps the glass against the 6-inch flexible scale *H*, which is held on the aluminum arc by brass clips. The two sides of the instrument are similar.

The distance between the points of the screws in the two rings when spaced on the specimen by jig *D* is 30 inches. This is the gage length. The distance between the axis of the specimen, when the specimen is concentric with the ring, and the outside face of the flexible scale is 19 inches. The arms extending from the rings and the pointers are 1-inch and ⅝-inch steel tubes, respectively; both are about 0.028 inch in thickness.

The scales were graduated to 0.01 inch. By using a magnifying

glass the readings were made to 0.001 inch. The two scale readings were taken simultaneously for each increment of applied torque until the yield point was reached. The instrument was then dismantled by removing the balanced pointers and loosening the screws in the rings. The torque was increased to obtain the ultimate strength,

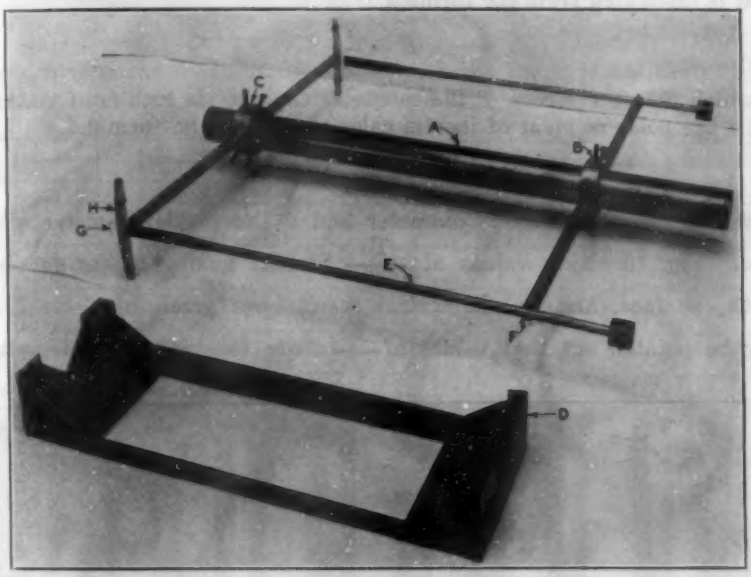


FIG. 8—TWIST METER ASSEMBLED ON A SPECIMEN AND SPACING JIG

TABLE 4.—*Results of tensile tests of full section to obtain stress-strain curves*

Tube No.	Type of treatment	Nominal size		Wall thickness		Stress at proportional limit	Yield point	Ultimate strength	Elongation—		Modulus of elasticity
		Outside diameter	Wall thickness	Minimum	Maximum				In 8 inches	In 2 inches	
		Inch	*Inch*	*Inch*	*Inch*	*Lbs./in.²*	*Lbs./in.²*	*Lbs./in.²*	*Per cent*	*Per cent*	*Lbs./in.²*
43	D	1	0.028	0.030	0.030	37,000	53,650	58,350	8.4	17.0	28,460,000
44	D	1	.035	.035	.036	39,000	48,050	52,400	14.2	32.5	28,890,000
108	D	1	.049	.049	.050	37,600	50,300	57,000	10.0	24.5	29,600,000
30	C	1	.065	.064	.066	30,400	34,900	47,020	33.2	53.5	28,140,000
93	A	1	.065	.064	.065	32,400	51,050	58,250	12.0	29.5	28,410,000
92	B	1	.065	.065	.066	40,800	61,100	62,500	6.1	17.5	28,730,000
73	C	1	.083	.079	.081	40,000	56,000	61,500	10.6	25.5	28,580,000
74	B	1	.083	.081	.083	40,000	49,500	59,000	15.4	31.5	28,580,000
75	C	1	.083	.080	.081	32,000	37,150	49,300	29.5	48.0	28,700,000

Symbol	Type of treatment	Symbol	Type of treatment
A	As-welded.	D	Rolled.
B	Swaged.	E	Cut-burr.
C	Swaged-annealed.	H	Hard-rolled.

and the specimen was twisted until it buckled and bent too much to keep the weighing head of the machine in line.

None of the torsion specimens showed any fracture in the weld. Fig. 9 shows some of the torsion specimens.

For circular tubes the stress in the extreme fiber at the proportional limit is calculated from the formula

$$S = \frac{Tc}{J}$$

in which S is the stress, T the torque, c the outside radius of the tube, and J the polar moment of inertia calculated from the formula

$$J = \frac{3.1416\ (D' - d')}{32}$$

in which D is the outside diameter and d the inside diameter of the tube. Fig. 10 shows values of $\frac{Tc}{J}$ plotted against shearing strain at the surface, and the numerical results are given in Table 5. It may be pointed out that values of $\frac{Tc}{J}$ above the proportional limit do

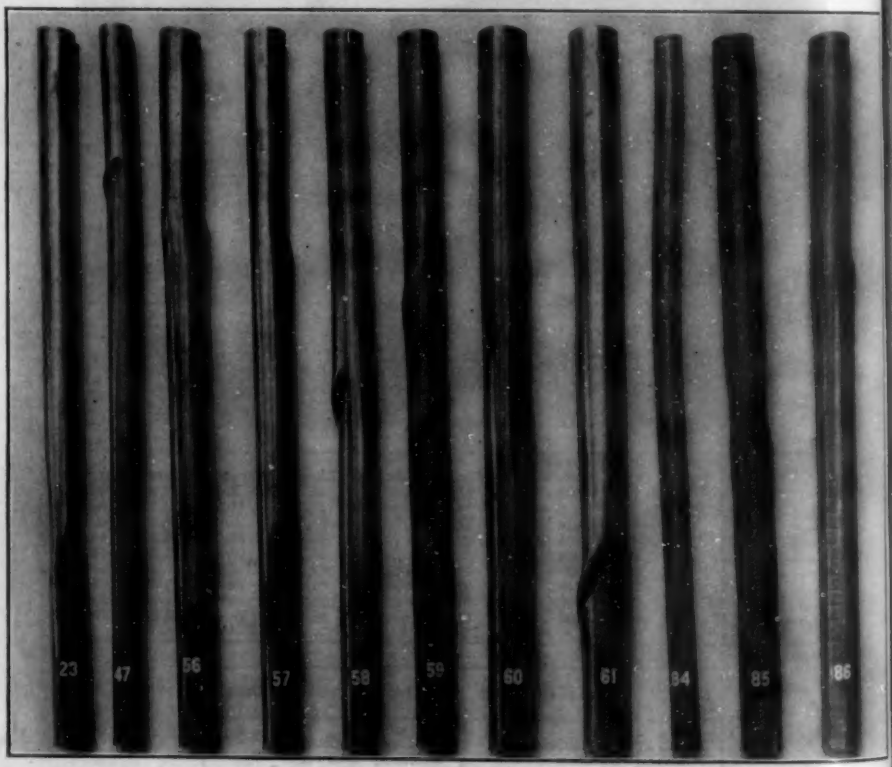


FIG. 9—TYPICAL TORSION SPECIMENS

not represent stress in the extreme fiber unless the tube is sufficiently thin to justify assuming a uniform distribution of shearing stress across the thickness of the tube.

The modulus of elasticity in torsion may be calculated from the formula

$$G = \frac{S}{u}$$

in which G is the modulus of elasticity, S the proportional limit, and u the shearing strain at the proportional limit.

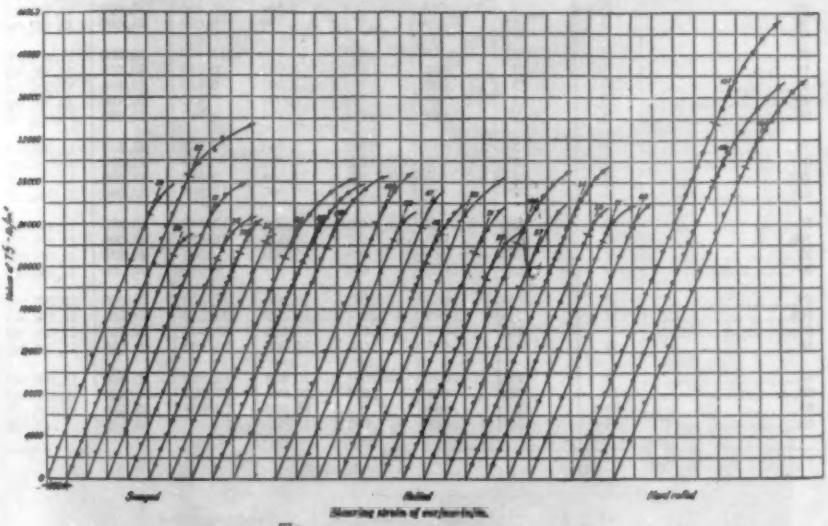


FIG. 10—RELATION OF $\frac{Tc}{J}$ TO SHEARING STRAIN AT SURFACE, TORSION TEST

5. HYDROSTATIC TEST

This test was made on tubes 1 inch and 2 inches in outside diameter, because tubes of these sizes are made in a wide range of wall thicknesses and in all types of treatment. The specimens were 17 inches long and cut to length with a hack saw.

The fixtures for closing the ends of the 2-inch tubes are shown in Fig. 11. Spanner wrenches A are used to screw the shell F over the grip B, thereby forcing the inside-tapered ring C over the tapered segments of the grip. The thin ring D is of bronze, which reduces the friction, and the ring E is a filler which in effect increases the length of C and bears on a shoulder on the inside of shell F. The inside of the segments of grip B have circumferential ribs which fit between the ribs on the solid plug G when in place on the tube. As the shell is screwed over the grip, the wall of the tube is compressed between the segments of grip C and plug G, making a tight joint and preventing the plug from slipping. Leaks around the plug are prevented by wrapping a layer of friction tape between the ribs.

TABLE 5.—*Results of torsion tests*

Tube No.	Type of treatment	Nominal size		Wall thickness, average	Torque at proportional limit	Ultimate torque	Shearing[1] stress in extreme fiber at proportional limit	Modulus[2] of elasticity in shear
		Outside diameter	Wall thickness					
		Inches	*Inch*	*Inch*	*In.-lb.*	*In.-lb.*	*Lbs./in.*[2]	*Lbs./in.*[2]
32	B	1	0.049	0.050	1,700	2,530	25,020	12,150,000
108	D	1	.049	.049	1,600	2,470	24,100	12,300,000
109	D	1	.065	.063	1,850	2,500	22,480	12,000,000
92	B	1	.065	.065	2,400	3,390	28,620	11,930,000
20	B	1½	.065	.064	4,200	6,580	21,060	12,460,000
84	B	1¾	.120	.123	10,000	17,100	20,880	11,600,000
11	B	2	.035	.035	5,000	6,540	23,920	12,520,000
47	D	2	.035	.035	5,000	6,310	23,850	11,920,000
48	D	2	.049	.050	6,000	9,450	20,400	12,360,000
90	B	2	.049	.052	6,250	9,940	20,690	11,960,000
70	B	2	.065	.062	7,500	10,990	21,310	12,200,000
51	D	2	.065	.062	7,600	10,840	21,270	11,880,000
107	H	2	.065	.066	12,500	18,020	33,530	11,980,000
49	H	2	.065	.066	10,600	17,300	28,040	11,780,000
50	D	2	.083	.081	8,500	13,740	18,870	11,940,000
106	D	2	.083	.081	10,000	16,400	22,200	12,330,000
23	B	2¼	.049	.048	8,000	9,560	22,270	12,040,000
88	D	2½	.035	.034	7,800	9,610	24,300	12,530,000
87	D	2½	.065	.061	10,000	17,730	17,940	12,370,000
104	H	2½	.065	.061	16,500	25,050	29,350	11,470,000
86	D	2½	.083	.081	17,200	25,960	23,750	12,000,000
59	D	2½	.083	.081	16,600	23,190	22,980	11,720,000
85	B	2½	.095	.097	17,400	32,750	20,460	11,600,000
86	B	2¾	.083	.084	20,000	33,870	21,860	12,280,000
61	D	3	.065	.062	18,400	25,920	22,430	12,190,000
60	D	3	.083	.080	24,800	33,600	22,080	11,840,000

[1] Shearing stress in extreme fiber $S = Tc/J$. [2] Modulus of elasticity in shear $G = S/\alpha$.

Symbol	Type of treatment	Symbol	Type of treatment
A	As-welded.	D	Rolled.
B	Swaged.	E	Cut-burr.
C	Swaged-annealed.	H	Hard-rolled.

The other fixture *I* is similar and is assembled as shown on specimen *K*. The plug on the inside of the tube has a small hole drilled through its axis and is tapped for a connection with the copper tube *H* which connects to a pump. Specimen *J* has been annealed at the ends to make the gripping easier.

The same fixtures were used for testing 1-inch tubes, except that an adapter was fastened on the inside of the 2-inch grips. A different set of plugs was used for each thickness of wall.

After the ends of the specimen were closed, care was taken to fill the specimen with water to remove all the air. The copper tube was then connected to the pump as shown in Fig. 12. The pressure was increased slowly until the tube fractured.

A check valve below the pressure gage retained the maximum pressure on the gage and prevented rapid return of the needle when the tube

fractured. A release valve was used to release the pressure on the gage. The rated capacity of the pump was 10,000 lbs./in.^{2}

After the grips were released, the plugs were still held in the tube

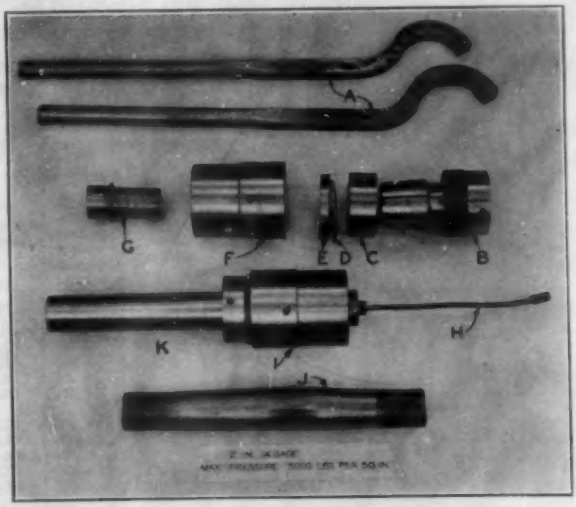


FIG. 11—FIXTURES FOR CLOSING THE ENDS OF 2 INCH TUBES FOR HYDROSTATIC TEST

FIG. 12—HYDROSTATIC TESTING EQUIPMENT

because the metal had been compressed beetween the ribs of the plugs. The plugs were removed by pulling them out in a testing machine.

The bursting strengths, given in Table 6, were calculated from the formula

$$S = \frac{Pd}{2t}$$

in which S is the bursting strength, P the bursting pressure, d the

TABLE 6.—*Results of hydrostatic test*

Tube No.	Type of treatment	Nominal size		Wall thickness, average	Maximum hydrostatic pressure	Bursting strength	Distance between fracture and weld
		Outside diameter	Wall thickness				
		Inches	*Inch*	*Inch*	*Lbs./in.²*	*Lbs./in.²*	*Inches*
34	A	1	0.028	0.028	3,500	60,950	0.62
35	B	1	.028	.028	3,700	62,550	.53
43	D	1	.028	.030	4,000	62,850	1.20
63	A	1	.035	.034	4,200	59,900	.15
97	A	1	.035	.032	4,400	66,500	.25
76	E	1	.035	.034	4,400	62,100	1.55
64	B	1	.035	.034	4,500	61,900	1.48
77	B	1	.035	.034	4,700	64,400	1.50
98	B	1	.035	.032	4,600	67,250	1.43
78	C	1	.035	.036	3,000	38,800	0
44	D	1	.035	.036	4,600	59,300	1.27
31	A	1	.049	.048	6,100	59,200	.30
32	B	1	.049	.050	6,900	62,300	.40
33	C	1	.049	.050	5,800	52,350	.40
108	D	1	.049	.049	6,600	60,750	1.05
93	A	1	.065	.064	8,400	59,250	.37
92	B	1	.065	.065	9,300	62,200	.60
30	C	1	.065	.065	6,900	46,250	0
109	D	1	.065	.063	7,500	52,200	1.14
73	E	1	.063	.060	11,000	59,700	(1)
74	B	1	.063	.062	11,500	58,600	(1)
75	C	1	.063	.061	9,500	49,150	0
10	A	2	.035	.036	2,300	62,700	.25
69	E	2	.035	.034	1,900	55,000	2.85
11	B	2	.035	.037	2,500	65,150	.25
		Inches	*Inch*	*Inch*	*Lbs. in.²*	*Lb./in.²*	*Inches*
12	C	2	0.035	0.035	1,800	49,700	0
47	D	2	.035	.035	2,300	63,600	1.91
91	A	2	.049	.051	3,000	56,450	2.35
90	B	2	.049	.052	3,200	58,250	.91
48	D	2	.049	.050	3,200	61,050	0
71	E	2	.065	.062	3,800	58,600	.60
70	B	2	.065	.062	3,900	59,150	2.42
72	C	2	.065	.063	3,400	50,700	0
51	D	2	.065	.062	4,000	60,500	2.15
49	H	2	.065	.066	5,400	76,400	3.00
107	H	2	.065	.066	5,900	83,500	.25
50	D	2	.083	.081	5,000	56,750	2.76
106	D	2	.083	.081	5,400	61,250	.46

Symbol	Type of treatment	Symbol	Type of treatment
A	As-welded.	D	Rolled.
B	Swaged.	E	Cut-burr.
C	Swaged-annealed.	H	Hard-rolled.

[1] The pressure required to produes fracture was above the capacity of the pump.

inside diameter, and t the wall thickness. The diameter d is the inside diameter of the tube before pressure was applied. On account of the ductility of most of the tubes the diameter d increased considerably before fracture occurred. If the bursting strength had been calculated from the actual diameter just before rupture it would have been higher, but this increase has no structural significance.

In this test there was a combination of longitudinal and transverse stresses, or two tensile stresses at right angles to each other. This condition tends to increase the bursting strength and accounts partly (probably largely) for the increase of bursting strength over the tensile strength of circumferential strips.

The shortest distance, along the circumference, between the fracture and weld is given in Table 6. Fig. 13 shows the positions of the fractures relative to the weld, and Fig. 14 shows graphically the bursting strengths and positions of fracture. The concentration of failures on either side of the weld and opposite the weld, as shown in Fig. 13, is in accordance with what may be expected from theoretical considerations if the welded portion of the tube has a higher yield point and consequently is stiffer than the rest of the tube after plastic deformation begins.[4] That this condition is a fact is shown (1) by the higher Rock-

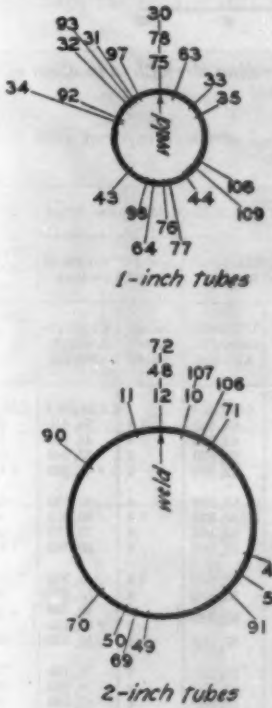


FIGURE 13.—*Diagram showing the location of fractures in hydrostatic specimens*

The tube number for each specimen is given on a radial line indicating the location of the fracture with respect to the weld

Types of treatment	Tube numbers
As-welded	34, 63, 97, 31, 93, 10, 91.
Cut-burr	76, 69, 71.
Swaged	64, 77, 98, 32, 92, 11, 90, 70, 35.
Swaged-annealed	78, 33, 30, 75, 12, 72.
Rolled	43, 44, 108, 109, 47, 48, 51, 50, 106.
Hard-rolled	49, 107.

[4] A. Ostenfeld, Teknisk Elasticitetslaere, 4th ed., Copenhagen, 1924, pp. 518 ff. or A. E. H. Love, The Mathematical Theory of Elasticity, 4th ed., Cambridge, 1927, Art. 274, p. 423.

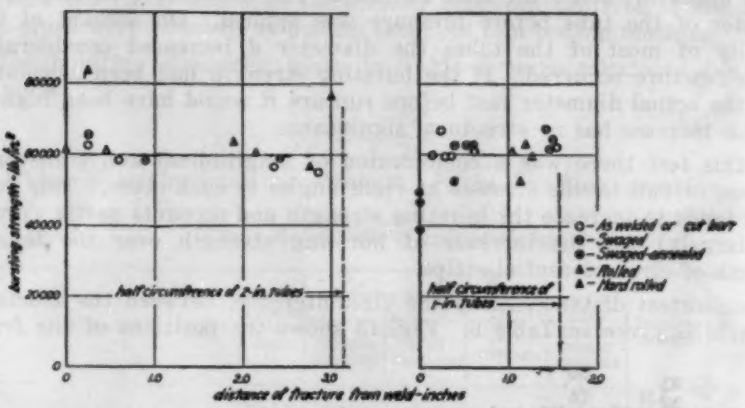


FIGURE 14.—*Graph showing the relation of bursting strength to location of fracture, hydrostatic test*

TABLE 7.—*Results of tensile tests of circumferential strips compared with results of hydrostatic test*

Tube No	Type of treatment	Nominal size		Wall thickness, average	Tensile test of circumferential strips				Hydrostatic test—bursting strength
					Weld outside of tested section		Weld in center of tested section		
		Outside diameter	Wall thickness		Number tested	Ultimate strength, average	Number tested	Ultimate strength, average	
		Inches	*Inch*	*Inch*		*Lbs./in.*[2]		*Lbs./in.*[2]	*Lbs./in.*
10	A	2	0.035	0.036	2	54, 890	[1] 4	54, 440	62, 700
69	E	2	.035	.034	2	45, 780	[1] 4	46, 960	55, 000
11	B	2	.035	.037	2	58, 920	4	55, 940	65, 150
12	C	2	.035	.035	2	52, 300	4	[3] 46, 800	[3] 49, 700
47	D	2	.035	.035	2	55, 000	4	58, 050	63, 000
91	A	2	.049	.051	2	50, 220	[1] 4	50, 970	56, 450
90	B	2	.049	.052	2	53, 150	4	53, 180	58, 250
48	D	2	.049	.050	2	60, 100	4	60, 140	[3] 61, 050
71	E	2	.065	.062	2	55, 640	[1] 4	53, 310	58, 000
70	B	2	.065	.062	2	53, 670	4	55, 280	59, 150
72	C	2	.065	.063	2	52, 920	2	49, 200	[3] 50, 700
51	D	2	.065	.062	2	57, 700	2 4	[3] 48, 410 50, 420	60, 500
49	H	2	.065	.066	2	71, 220	2	71, 100	76, 400
107	H	2	.065	.066	1	82, 000	2	78, 920	83, 500
50	D	2	.083	.081	2	50, 650	4	52, 000	56, 750
106	D	2	.083	081	1	60, 550	2	60, 910	61, 250

[1] The burrs on two of these specimens were ground off to uniform thickness.
[2] Fractured in the weld.

Symbol	Type of treatment	Symbol	Type of treatment
A	As-welded.	D	Rolled.
B	Swaged.	E	Cut-burr.
C	Swaged-annealed.	H	Hard-rolled.

well numbers in the welded portion, indicating a higher ultimate strength and probably a higher yield point, inasmuch as the material in the welded portion and in the rest of the tube is similar and (2) by the tests on the circumferential strip which yielded outside the welded portion in every case except in the case of the swaged-annealed tubing.

The 2-inch hydrostatic specimens are shown in Fig. 15. Some of the 1 and 2 inch hydrostatic specimens are shown in Figs. 16 and 17 in greater detail.

6. Tensile Test of Weld

This test was made on tubes 2 inches in outside diameter, because this size when cut and opened into a strip would form a specimen long enough for milling a reduced section. (See Fig. 18.)

To compare the tensile strength of the base metal and of the welds, simi-

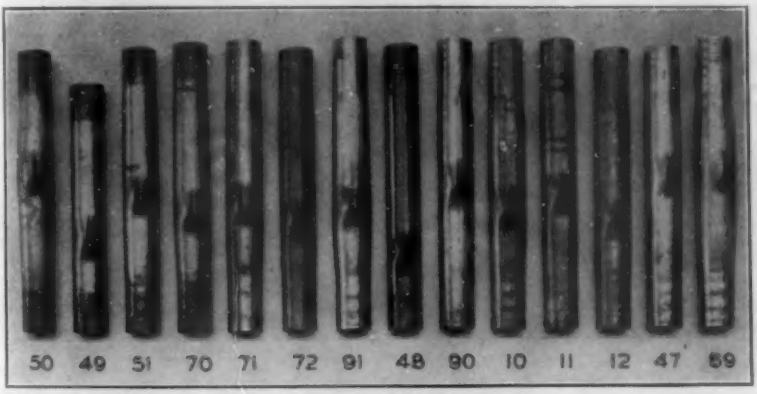


Fig. 15—Hydrostatic Specimens of 2-Inch Tubes

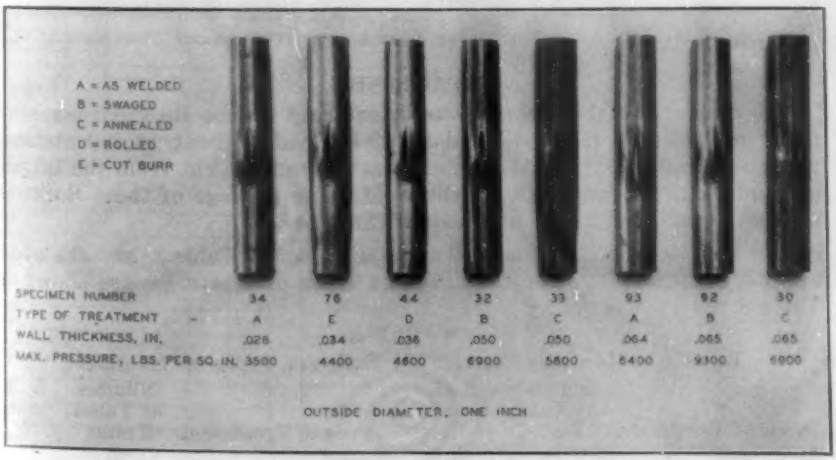

A = AS WELDED
B = SWAGED
C = ANNEALED
D = ROLLED
E = CUT BURR
SPECIMEN NUMBER 34 76 44 32 33 93 92 30
TYPE OF TREATMENT A E D B C A B C
WALL THICKNESS, IN. .026 .034 .036 .050 .050 .064 .065 .065
MAX. PRESSURE, LBS. PER SQ. IN. 3500 4400 4600 6900 5800 8400 9300 6900
OUTSIDE DIAMETER, ONE INCH

Fig. 16—Fractured Portion of Some 1-Inch Hydrostatic Specimens

lar specimens were prepared, some having no welds, others having welds at the middle of the reduced section.

The tubes were chucked in a lathe and rings 1¼ inches long cut from the end. Some of the rings from each tube were cut at the weld parallel to the axis; others were cut diametrically opposite the weld. The rings were straightened and tensile specimens having a reduced section, three-fourths inch wide, machined from them. These untested specimens are shown in Fig. 18 above some of the tested specimens. The burrs on some of the welded specimens from as-welded and cut-burr tubes were ground off to make the thickness of the specimen uniform at the weld. This eliminated any additional strength at the weld due to the increase of cross-sectional area formed by the small burr.

The average tensile strength and the position of fracture are given in Table 7 for comparison with the results of the hydrostatic test of the same tube. Fig. 18 shows one welded specimen from each of the tubes tested, excepting tubes 106 and 107.

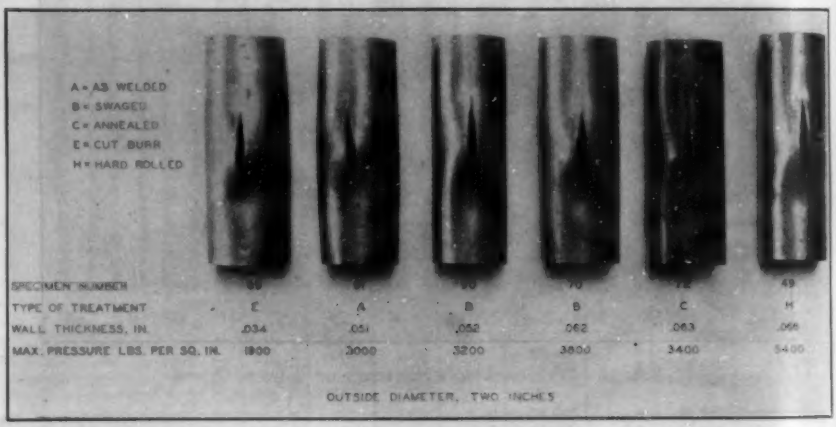


FIG. 17—FRACTURED PORTION OF SOME 2-INCH HYDROSTATIC SPECIMENS

7. HARDNESS

The hardness of the tubing was determined by the Rockwell machine, using a 1/16-inch steel ball and a 100-kg load. About 10 indentations were uniformly distributed around a short specimen cut from the length, one indentation being made on the weld. The average of these Rockwell numbers was taken as the hardness of the tube.

The Rockwell number for each tube is shown in Table 2, and the average Rockwell numbers for the different types of treatment are shown in Table 8.

TABLE 8

Results of Hardness Test for the Different Types of Treatment

Types of Treatment	Number of Tubes Tested	Rockwell No.	Types of Treatment	Number of Tubes Tested	Rockwell No.
As-welded	18	66.6	Rolled	20	74.1
Cut-burr	4	64.3	Hard-rolled	3	86.5
Swaged	24	72.2	Swaged-annealed ...	19	54.5

Since high Rockwell numbers were found at the weld, a few specimens of tubing having an outside diameter of 2 inches were selected for a special study of the variation in Rockwell numbers around the tube. The short specimen was cut longitudinally into three segments. Each segment was placed on the bearing block so as to make the indentations on the inside and along a helical line around the tube, the indentations being spaced about one-thirty-second inch circumferentially. The results are shown in Fig. 19.

Similar readings were not made upon tubes of other diameters because it was believed that the readings on the 2-inch tubes, having medium thick walls, showed the variations in Rockwell numbers which might be expected in any tubing made by the same process.

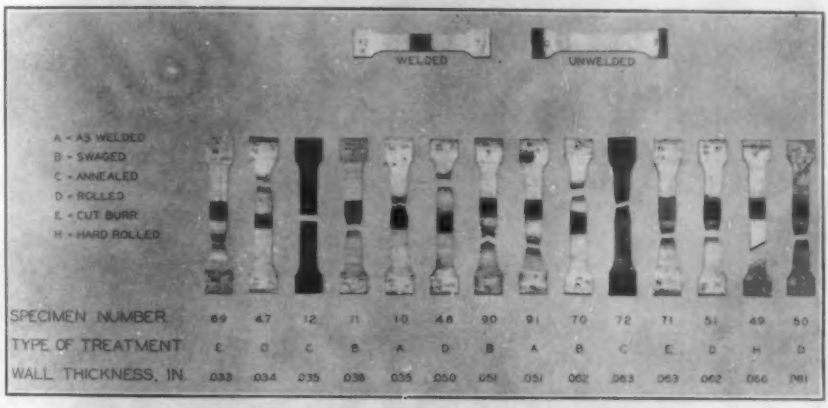

WELDED
UNWELDED
A = AS WELDED
B = SWAGED
C = ANNEALED
D = ROLLED
E = CUT BURR
H = HARD ROLLED
SPECIMEN NUMBER 69 47 12 71 10 48 90 91 70 72 71 51 49 50
TYPE OF TREATMENT E D C B A D B A B C E D H D
WALL THICKNESS, IN. .033 .034 .035 .038 .035 .050 .051 .051 .062 .063 .063 .062 .066 .061

FIG. 18—TENSILE SPECIMENS FROM CIRCUMFERENTIAL STRIPS

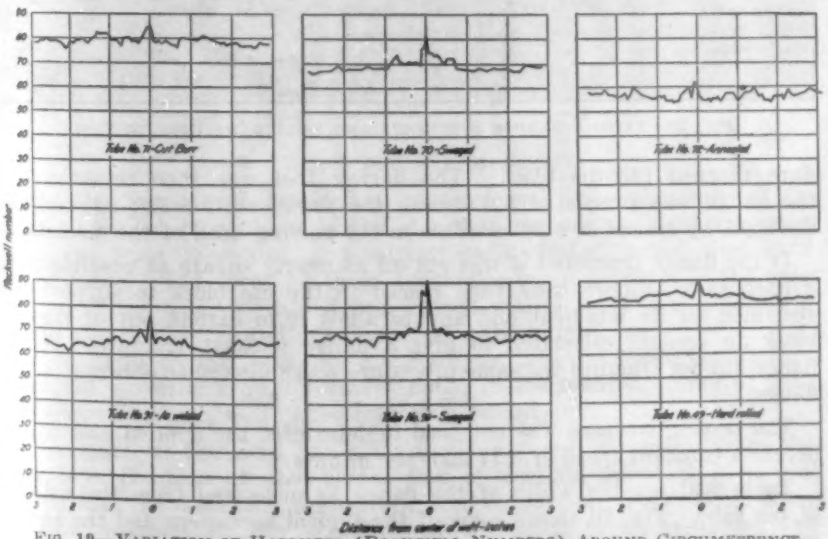


FIG. 19—VARIATION OF HARDNESS (ROCKWELL NUMBERS) AROUND CIRCUMFERENCE OF TUBES

8. Flanging Test

The flanging equipment was designed as recommended in the A. S. T. M. specifications A-83-27 for flanging tests, except that the flaring tool, as shown in Fig. 20, was made large enough to form the maximum possible flange on 1 and 2 inch tubes.

Specimens, about 4½ inches long, were cut from the tube in a lathe. The specimen extended out of the die block (Fig. 20) about three-fourths inch when both were resting on a flat surface on the weighing table of the testing machine. The flaring tool was placed in the end of the specimen and forced down by the moving head of the machine until the

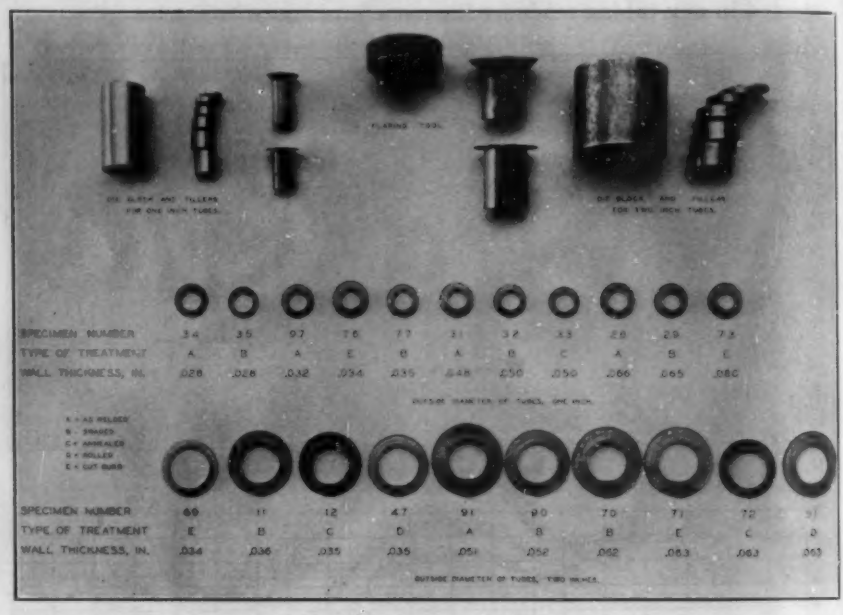

SPECIMEN NUMBER 34 35 97 76 77 31 32 33 28 29 73
TYPE OF TREATMENT A B A E B A B C A B E
WALL THICKNESS, IN. .028 .028 .032 .034 .035 .048 .050 .050 .066 .065 .060
SPECIMEN NUMBER 69 11 12 47 91 90 70 71 72 91
TYPE OF TREATMENT E B C D A B B E C D
WALL THICKNESS, IN. .034 .036 .035 .035 .051 .052 .062 .063 .063 .063

Fig. 20—Typical Flange Specimens and Equipment Used in Test

flare reached the die block. The flaring tool was then removed and the flange was completed by forcing the flared section flat against the die block by means of a flat surface in the moving head of the machine.

If the flange fractured it was cut off as nearly square as possible with a hack saw. Fillers were then placed in the die block to support the specimen on its lathe-cut end and to allow it to extend out of the die block an amount estimated to give a flange without fracture. If the flange did not fracture the same procedure was followed to obtain a larger flange.

The testing machine was not used to determine the applied load but to obtain a constant speed of 0.44 inch per minute.

Table 9 shows the width of the flange as measured from the outside of the tube. Fig. 20 shows some of the typical specimens and the equipment used.

TABLE 9.—*Results of flanging test*

Tube No.	Type of treatment	Nominal size		Wall thickness, average	Width of flange
		Outside diameter	Wall thickness		
		Inches	*Inch*	*Inch*	*Inch*
34	A	1	0.028	0.028	0.30
35	B	1	.028	.028	.21
76	E	1	.035	.034	.35
64	B	1	.035	.034	.25
63	A	1	.035	.034	.26
97	A	1	.035	.032	.28
98	B	1	.035	.032	.20
77	B	1	.035	.034	.27
31	A	1	.049	.048	.31
32	B	1	.049	.050	.30
33	C	1	.049	.050	.20
108	D	1	.049	.049	.30
109	D	1	.065	.063	.28
28	A	1	.065	.066	.30
92	B	1	.065	.065	.28
29	B	1	.065	.065	.30
73	E	1	.083	.080	.30
60	E	2	.035	.034	.33
11	B	2	.035	.037	.58
12	C	2	.035	.035	.50
47	D	2	.035	.035	.47
91	A	2	.049	.051	.77
90	B	2	.049	.052	.58
71	E	2	.065	.062	.67
70	B	2	.065	.062	.70
72	C	2	.065	.063	.40
51	D	2	.065	.062	.60
107	H	2	.065	.066	.40
106	D	2	.083	.081	.50

Symbol	Type of treatment	Symbol	Type of treatment
A	As-welded.	D	Rolled.
B	Swaged.	E	Cut-burr.
C	Swaged-annealed.	H	Hard-rolled.

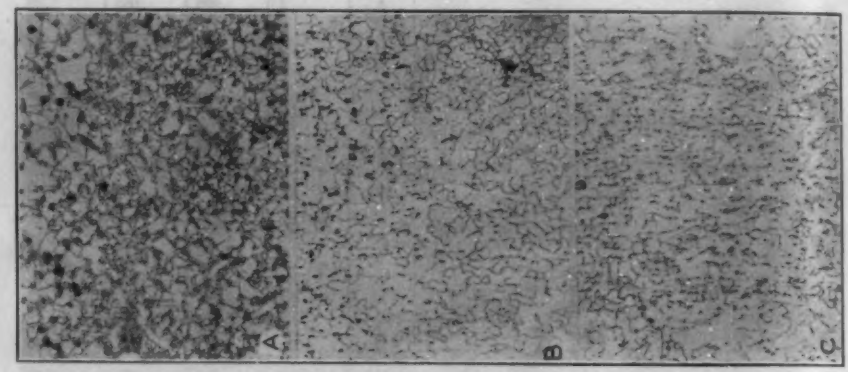
9. MICROSCOPIC EXAMINATION

For the purpose of examining microscopically the structure of the metal of the tubing at the weld and at a distance from the weld, specimens were cut from as-welded, swaged, swaged-annealed, rolled, and hard-rolled tubes. The faces of these specimens corresponding to the cross section of the tubes were polished, etched with a 5 per cent solution of picric acid in alcohol, and examined under the microscope.

Figs. 21 to 25, inclusive, are micrographs, taken at the magnifications indicated, showing typical features noted in the microstructure of these specimens and discussed in the following paragraphs.

The metal at the weld has a distinctly different structure from that outside of the zone affected by the heat of welding, but there is no indication that the metal has been overheated or burned. Figs. 21 *A*, *B* and *C* show, respectively, the structure of the metal in an as-welded tube specimen at the weld, immediately adjacent to the weld, and the portion

of the tube opposite to the weld. The dark-colored patches shown at a low magnification in these micrographs, some as fuzzy masses and others as sharply outlined specks, are carbon-bearing areas. Those areas present at the weld were noted at higher magnifications to be usually grains of sorbitic pearlite. The size of the ferrite grains (colorless) noted in the metal usually at or near the weld, are in some specimens larger than in the base metal. This is apparent in Fig. 22. Several specimens showed a decided absence of carbon-bearing areas, even in the portion of the tube opposite to the weld, as illustrated in Fig. 22 *B*. This is sometimes found in low-carbon steel.



Photographs reduced to 2/3 original size

FIG. 21—MICROSTRUCTURE OF SPECIMEN OF AS WELDED TUBE, TAKEN AT THREE LOCATIONS IN CROSS SECTION. ×60

A. At the weld. Note the fuzzy dark-appearing patches which are the carbon bearing areas. *B*. Immediately adjacent to the weld. The upper half containing the sharply outlined dark specks is adjacent to the weld. *C*. Opposite to the weld. Normal structure of the unaffected metal. Etchant: 5 per cent solution of picric acid in alcohol (for Figs. 21-25, inclusive). (Tube No. 10: 2 inches outside diameter; wall thickness 0.035 inch)

Photographs reduced to 60 per cent of original size

FIG. 22—MICROSTRUCTURE OF SPECIMEN OF AS WELDED TUBE, TAKEN AT TWO LOCATIONS IN CROSS SECTION. ×100

A. At the weld. *B*. Opposite to the weld. (Tube No. 93: 1 inch outside diameter; wall thickness 0.065 inch)

Figs. 22 *A* and 23 show the line of weld in as-welded and swaged tubes having a wall thickness of 0.065 inch. The mechanical tests show that there was no indication of weakness at the weld even for the tubes the photomicrographs of which showed a line at the weld. In all cases the merging together of the metal at the weld joint appears to have been quite complete.

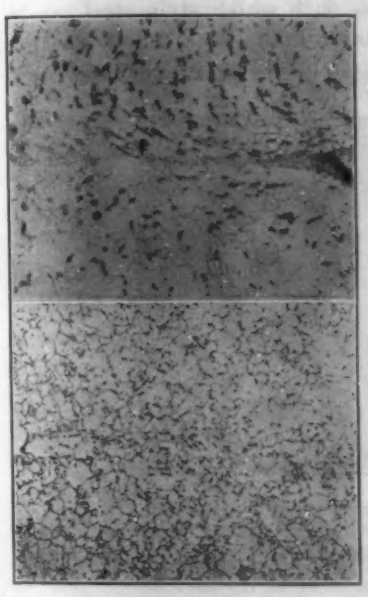


FIG. 23 — MICROSTRUCTURE OF SPECIMEN OF SWAGED TUBE, TAKEN IN CROSS SECTION AT THE WELD. ×100

Note the appearent distortion of the metal at the line of weld, as evidenced by the arrangement of the dark-colored patches. (Tube No. 92: 1 inch outside diameter; wall thickness 0.065 inch)

Photograph reduced about 60 per cent of original size

FIG. 24 — MICROSTRUCTURE OF SPECIMEN OF SWAGED-ANNEALED TUBE, TAKEN IN CROSS SECTION AT THE WELD. ×100

The line of weld appears to have been affected by the annealing treatment following the swaging operation. (Tube No. 12: 2 inches outside diameter; wall thickness 0.035 inch)

Photograph reduced about 60 per cent of original size

The annealing following the swaging operation in the swaged-annealed tube appears to have removed in a quite effective manner the effect produced by the welding upon the structure of the metal at and near the weld and to have produced a quite uniform structure throughout the tube section. Fig. 24 shows the structure of the metal at the weld in a tube having a wall thickness of 0.035 inch; this structure is not much different from that in the portion of the tube opposite to the weld. The 0.065 inch thick tubing showed similar results.

In the rolled tubes the ferrite grains at and near the weld were elongated by the rolling, while those in the portions outside of the weld zone and the area covered by the rolling operation appeared to have been unaffected; that is, they remained more or less equiaxed. Figs. 25 *A* and *B* are typical of these two structures.

VI. DISCUSSION

1. VARIATION OF OUTSIDE DIAMETER

The swaged tubes had the most nearly constant outside diameter, as shown in Fig. 3. The maximum difference of the four measurements was 0.008 inch, and 88 per cent of these tubes had a maximum difference of only 0.003 inch.

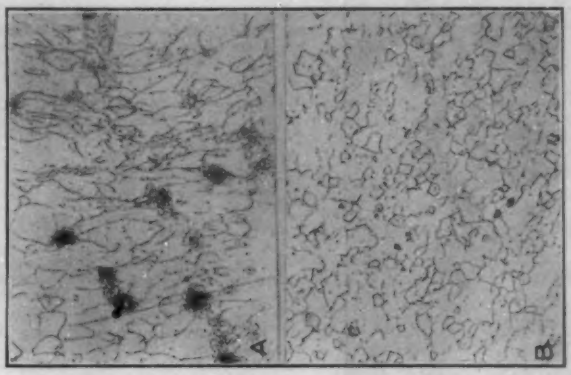
The maximum difference of outside diameter of the rolled tubes was 0.009 inch, and 78 per cent had a maximum difference of 0.006 inch.

The maximum difference of outside diameter of the swaged-annealed tubes was 0.018 inch, and 85 per cent had a maximum difference of 0.006 inch.

2. Variation of Thickness of Wall

Because of the uniformity of thickness with which strip steel can be rolled, the finished tube will also have this uniformity.

With the exception of the welds in the as-welded, cut-burr, and rolled



Photographs reduced to about 60 per cent of original size

Fig. 25—Microstructure of Specimen of Rolled Tube, Taken at Two Locations in Cross Section. ×100

A. At the weld. *B*. 90° from the weld. The ferrite grains at the weld appear deformed while those in the portions away from the weld have been unaffected; that is, are in a more or less equiaxed condition. (Tube No. 108; 1 inch outside diameter; wall thickness 0.049 inch)

tubes, but including the weld in swaged and swaged-annealed tubes, the maximum difference in thickness of wall was 0.003 inch; 93 per cent showed a maximum difference of 0.002 inch and 57 per cent a maximum difference of 0.001 inch.

3. Tensile Test of Full Section

By varying the cold working a wide range of strengths can be obtained without appreciable change in the carbon content of the steel.

The hard-rolled tubes had, on an average, the highest tensile strength and the lowest elongation. The swaged and the rolled tubes had practically the same tensile strength. The swaged-annealed tubes had a lower tensile strength and a lower ratio of yield point to tensile strength but a considerable increase in elongation. This is shown in Table 3.

4. Axial Crushing Test

Cracks showed in some of the specimens at the weld on the outside edges of the folds, and these cracks seemed to be due, in most cases, to the difference in ductility between the weld and the base metal.

The hard-rolled tubes, Nos. 104 and 107, had a high ratio of yield point to ultimate strength and a low elongation in the tensile test. In axial crushing test these specimens failed by leaning over and crinkling locally at the top and the bottom on opposite sides of the specimen. This is probably due to the high ratio of yield point to ultimate strength and low ductility in compression.

5. Torsion Test

In most of the tubes the failure occurred by buckling of the thin wall for a comparatively short distance. This failure is shown in Fig. 9 for tubes Nos. 47, 58, and 61, and for these thin tubes may be explained by the compressive stresses on planes making an angle of approximately 45 deg. with the axis.

In the tubes with thicker walls, for example, tube No. 84, the tube keeps its circular cross section and the specimen twists quite uniformly along its entire length.

The buckling did not begin at the weld of any of the specimens. None of the specimens fractured in the weld or in the base metal.

6. Hydrostatic Test

The bursting strength of the tube was higher than the tensile strength of the circumferential strips cut from the tube. This increase of strength is probably due largely to the combination of longitudinal and transverse tensile stresses.

With the exception of the annealed tubes, only one specimen, rolled tube No. 48, fractured in the weld. The bursting strength of this tube was higher than that of a number of other rolled tubes which fractured outside of the weld.

Of the annealed tubes, one specimen, tube No. 33, fractured outside of the weld. The average bursting strength of the remainder was about 90 per cent of the bursting strength of the annealed specimen which did not fracture in the weld. This indicates that the annealing process reduces the strength of the weld about 10 per cent below that of the base metal.

Except for the annealed tubes, the locations of the fractures did not bear any definite relation to the welds. There is therefore no zone of weakness in the tube due to the welding operation.

7. Tensile Test of Weld

There was not a complete agreement of the position of fracture in this test with the position in the hydrostatic test. The hydrostatic specimen of tube No. 48 fractured in the weld, and all the circumferential strips fractured outside of the weld.

The fracture did not occur in the weld of any of the strips from as-welded or cut-burr tubes, nor did the fracture occur in the weld of any of the strips with the burrs ground off to make the thickness uniform at the weld. This showed that with the burr removed the weld was equally as strong as other elements of the tube in the reduced section.

The annealed specimens which fractured in the weld had a tensile strength equivalent to about 93 per cent of the base metal as determined by testing strips with the weld outside of the reduced section.

With the weld in the center as well as outside of the reduced section, comparative tensile strengths were obtained around the tube. These strengths did not indicate any zone of weakness near the weld.

8. Hardness

The curves showing the variation of hardness around the tube indicate that the welding operation slightly increases the hardness at the weld.

The swaging and rolling operations increase the hardness of the tube, and the hardness of the weld is correspondingly increased. There was no decrease of hardness adjacent to the weld of any of the tubes, but an increase at the weld as shown in Fig. 19. The hardness at the weld of the annealed tubes is practically the same as the hardness of the tube.

9. Flanging Test

The width of the flange is not a definite measure of the ductility of the tube at right angles to the axis because of the unknown factors which entered into this test. One of the unknown factors is the friction between the tube and the flaring tool, which seems to vary for the different tubes. Another factor is the compressive strength of the tube, for a number of the tubes started to crinkle below the flaring tool, due to the axial load, before the maximum flange could be formed.

VII. CONCLUSIONS

This investigation was made for the purpose of determining the physical properties of low carbon steel tubing. The tubing was formed from strip steel and electrically welded under pressure by the resistance method. The tubes varied in outside diameter from five-eighths inch to 3 inches and in wall thickness from 0.028 to 0.120 inch, inclusive. The results seem to warrant the following conclusions:

1. The maximum difference in the outside diameter of the swaged tubes (four measurements at 45 deg. intervals) was 0.008 inch, and 88 per cent of these tubes did not exceed 0.003 inch; for the rolled tubes the maximum difference was 0.009 inch, and 78 per cent did not exceed 0.006 inch; for the swaged-annealed tubes the maximum difference was 0.018 inch, and 85 per cent did not exceed 0.006 inch.

2. With the exception of the welds of the as-welded, cut-burr, and rolled tubes, but including the weld of the swaged and swaged-annealed tubes, the maximum difference of the four measurements of the wall thickness was 0.003 inch; 93 per cent did not exceed 0.002 inch, and 57 per cent did not exceed 0.001 inch.

3. For the swaged-annealed tubes the tensile strength was greater than the compressive strength. The average strengths are 51,000 lb./in.^{2} in tension and 46,000 lb./in.^{2} in compression. For the other tubes the strength was practically the same in tension and compression. The average value for as-welded and cut-burr tubes is 54,000 lb./in.,^{2} for swaged

tubes 58,000 lb./in.,² for rolled tubes 56,000 lb./in.,² and for hard-rolled tubes 74,000 lb./in.²

The average yield point in tension of the as-welded and cut-burr tubes was about 90 per cent of their average tensile strengths (minimum, 76 per cent), swaged tubes about 93 per cent (minimum, 83 per cent), rolled tubes about 91 per cent (minimum, 83 per cent), hard-rolled about 95 per cent (minimum, 93 per cent), and swaged-annealed tubes about 71 per cent (minimum, 67 per cent).

The average elongation of as-welded and cut-burr tubes in 2 inches was about 34 per cent and in 8 inches 20 per cent; of swaged tubes in 2 inches 28 per cent and in 8 inches 12 per cent; of rolled tubes in 2 inches 36 per cent and in 8 inches 15 per cent; of hard-rolled in 2 inches 8 per cent and in 8 inches 3 per cent; of swaged-annealed tubes in 2 inches 48 per cent and in 8 inches 31 per cent.

4. In the torsion test the average shearing stress in the extreme fibers at the proportional limit for the swaged tubes was 22,610 lb./in.,² for the rolled tubes 22,190 lb./in.,² and for the hard-rolled tubes 30,310 lb./in.² No fracture occurred in the weld or in the base metal of any of the specimens even when twisting was continued after the ultimate torque was reached.

5. In the hydrostatic test the average bursting strength of 10 as-welded and cut-burr tubes was 60,060 lb./in.,² of 9 swaged tubes 62,550 lb./in.,² of 9 rolled tubes 59,800 lb./in.,² of 2 hard-rolled tubes 79,950 lb./in.,² and of 6 swaged-annealed tubes 47,840 lb./in.² The bursting strengths of the tubes which failed near the weld were practically the same as those of the tubes which failed at a distance from the weld. The average bursting strength of the five swaged-annealed tubes that fractured in the weld was about 90 per cent of the bursting strength of the tube that fractured outside of the weld.

6. The average tensile strength of the circumferential strips cut from the tube was practically the same as the longitudinal tensile strength of the tube. An exception to this was the tensile strength of the strips from the two swaged-annealed tubes that fractured in the weld, and the average strength of these was about 93 per cent of the strength of the base metal.

7. The average Rockwell number, using a 1/16-inch steel ball and a 100-kg load, was about 65 for as-welded and cut-burr tubes, 73 for swaged and rolled tubes, 86 for hard-rolled tubes, and 54 for swaged-annealed tubes. There was a gradual increase of hardness near the weld of all tubes excepting the swaged-annealed, which were practically uniform.

8. The microscopic examination showed that there was no overheating or burning of the metal at the weld. The edges at the seam were heated to the welding temperature and immediately forced together. Apparently there are no more inclusions at the weld than in the base metal.

9. This investigation shows that, except in the case of swaged-annealed tubing, the properties of the base metal (the metal not affected by the welding operation) can be used in determining the working stresses for different structural uses of tubing made by the process used in the manu-

facture of this electrically welded tubing, no allowance being necessary for the altered structure in and adjacent to the weld. The properties at and near the weld for annealed tubing are sometimes slightly lower than the properties for the base metal.

A Study of Welded Metals Under Fatigue Tests*

By G. E. Thornton†

OBJECT

THE object of the tests undertaken in this work was for the purpose of comparing the different types of welds in which a flexure of the specimen occurs when subjected to continued series of stress reversals. Such a condition is present in a member under continuous or spasmodic vibration.

The tests were undertaken by the Department of Mechanical Engineering at the State College of Washington in cooperation with the American Bureau of Welding.

The field covered in this work consists of tests of oxyacetylene, resistance welds, and flash welds, and some work on atomic hydrogen and metallic arc welds.

APPARATUS

The apparatus used in connection with this work consisted of a bank of seven Farmer Type rotating beam testing machines. The construction of the machines was the construction usually employed when testing a short specimen.

The specimen A, Figure I, reduced at the center and tapered at the ends, was pressed into the end of the spindle which was machined to fit the end of the specimen. The specimen was securely held to the spindle at each end by means of a ¼-inch machine screw.

The two spindles with the specimen securely fastened between them were free to rotate in the set of four roller bearings, C D E F. Two of these bearings, C F, were mounted at the ends on trunnions resting in the slots on the end brackets X Y. The other two bearings with connecting cross bars formed a yoke which supported the weight W.

By varying the weight W any desired stress could be placed on the specimen to be tested.

The specimens were rotated by a one-fourth h.p. motor M direct connected by a universal coupling to the spindles holding the specimens.

The machine was shut down as soon as the specimen failed by means of a drop switch on the shaft holding the weight.

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* Paper to be presented at Fall Meeting, A. W. S., Chicago, September, 1930. Report rendered to Fundamental Research Committee, A. B. W.

† State College of Washington.

The number of reversals which each specimen completed was recorded upon a speed counter R connected to the end of the spindle opposite the driving motor.

SPECIMENS

The specimens for test were furnished by the General Electric Company, Union Carbide and Carbon Company, Air Reduction Sales Corporation, American Chain Company, and the welding shops of the Department of Mechanical Engineering, State College of Washington.

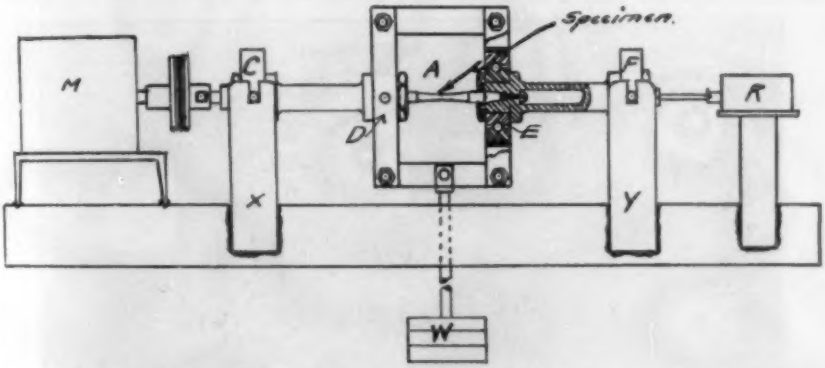


FIG. 1—LINE DRAWING SHOWING CONSTRUCTION OF FARMER TYPE ROTATING BEAM TESTING MACHINES USED IN FATIGUE TESTS

The specimens were made up by cutting cross sections from a test coupon formed by welding two ¾-inch by 2½-inch-bars of fire box steel 24 inches long, as shown in Figure IV.

The sections cut from the coupon were ¾ inch square and 5 inches long. These small sections were then turned down to ½ inch diameter and the center section reduced to .400 inch diameter (Figure V). The center section was reduced for the purpose of causing the specimen to fail in the weld. This procedure was successful in concentrating the flexure of the specimen at the weld and thus gave a means of comparison between the different types of welds.

The specimens were highly polished at the reduced section in order to eliminate the possibility of small depressions inducing failure when subjected to a bending stress.

The specimens were carefully placed in the rotating beam and fastened to the spindle to give a true, even rotation without vibration. The speed of rotation, 1750 r.p.m., was such that no whip was produced in the short specimen.

The same procedure was carried through for each of the tests on the various types of welds.

In determining a policy of securing specimens it was decided to test the small specimens in fatigue instead of the large specimens as advocated by some companies.

It was decided to obtain a true cross-section of the welding field by soliciting welded coupons from companies doing different types of welding. The average of these tests gives a lower result than would be obtained if one experienced man was doing all the welding with the knowledge that his welds were to be tested for test data.

The author feels that this cross-section of the entire field is much more of an indication of what to expect from welds than the best results obtained by any one individual.

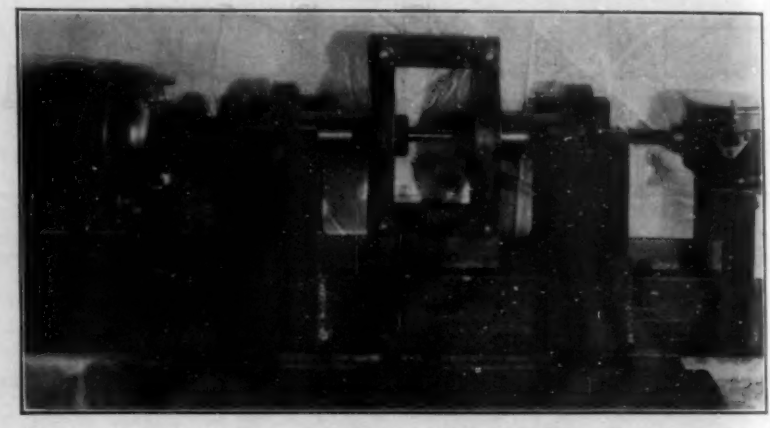


FIG. 2—CLOSE-UP VIEW OF FARMER TYPE ROTATING BEAM FATIGUE TESTING MACHINE. NOTICE METHOD OF CONSTRUCTION BY WELDING

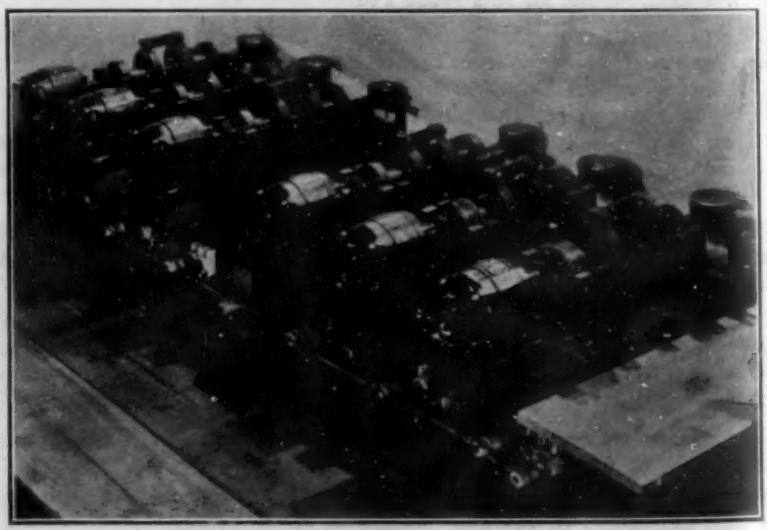


FIG. 3—BANK OF SIX FATIGUE MACHINES USED IN OBTAINING DATA ON FATIGUE OF WELDS. SAME CONSTRUCTION AS SHOWN IN FIG. 2

DATA

The determination of the stress and loads for the specimens used in the fatigue tests for rotating beam machines was calculated as for a simple beam supported at each end with two concentrated loads equidistant from the center.

The weight of the bushings, bearings, and yokes was considered in the weight W, necessary to produce the stress. The total weight of the bushings, bearings, and yoke was considered as being located one-half

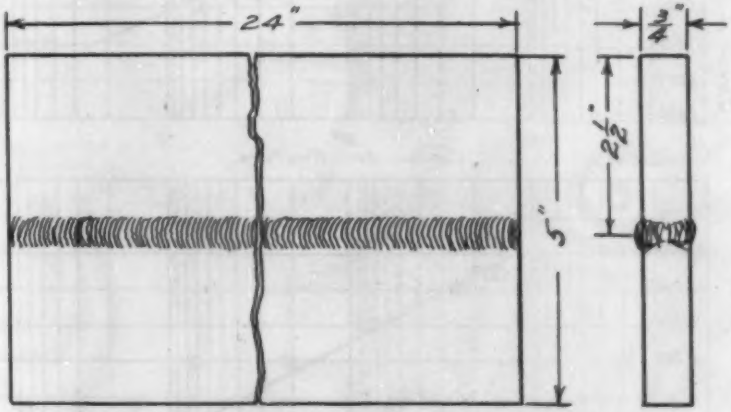


FIG. 4—METHOD OF MAKING UP COUPONS FROM WHICH SPECIMENS WERE CUT

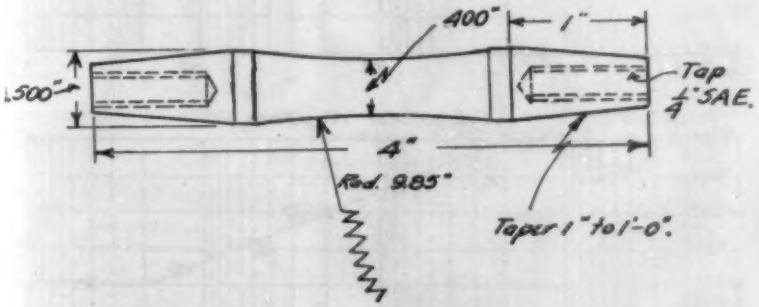
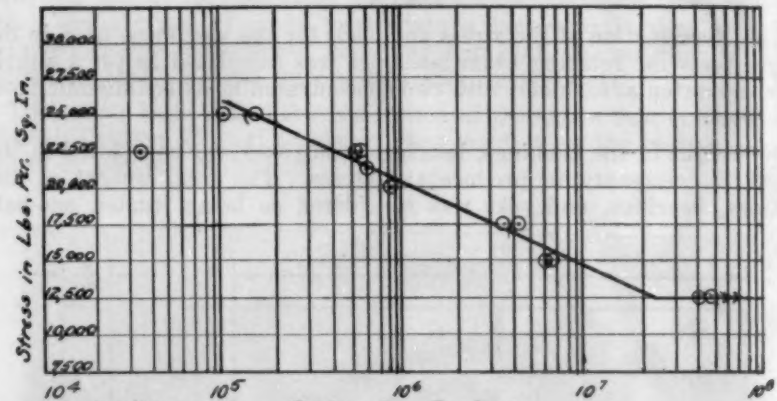


FIG. 5—LINE DRAWING OF FATIGUE SPECIMEN USED IN TESTS

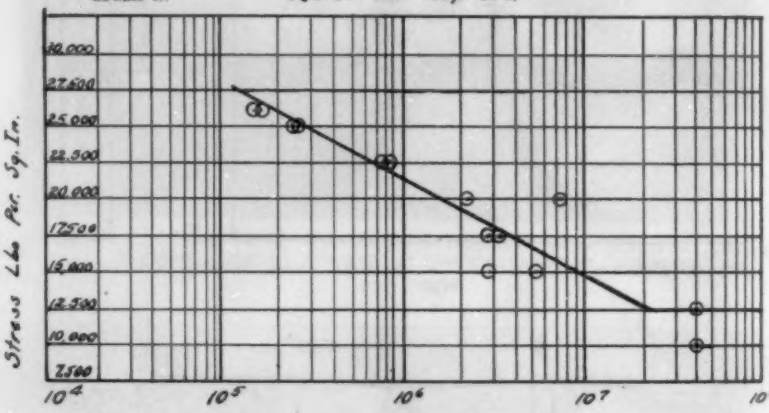
at either end of the yoke. The weight of the beam itself, being small, was neglected.

The trunnions supporting the ball bearings were set on a flat face to give as near line contact as possible, thus reducing friction to a negligible amount. By use of ball bearings the torsional stress applied to the specimen also became very small and was neglected in stress load calculations.

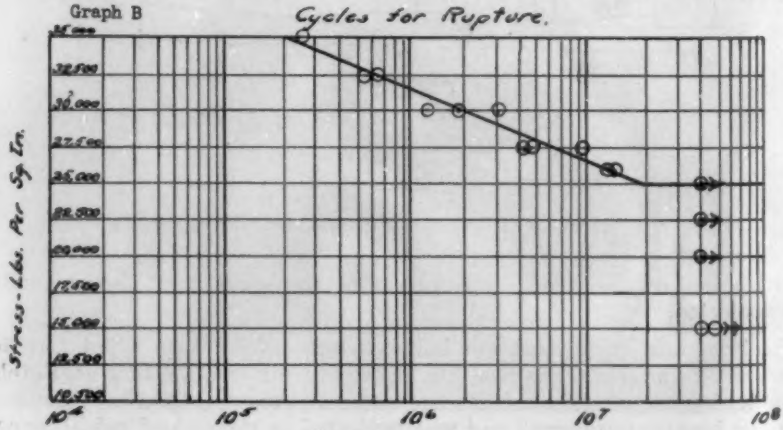
Data on representative samples taken from test coupons is given below for the type of weld indicated.



Graph A



Graph B



Graph C

Oxy-Acetylene Weld, Single V, Low Carbon Rod. Ratio of Oxygen to Acetylene 1.14

A1 Series—See Graph A

Stress	Specimen	Cycles for Failure
25,000	L	138,700
25,000	J	102,500
22,500	G	565,000
22,500	I	546,000
22,500†	H	31,000
21,500	O	600,000
20,000	K	822,000
17,500	D	3,600,000
17,500	F	4,080,000
15,000	C	6,380,000
15,500	B	6,120,000
12,500*	E	40,000,000
12,500*	M	40,000,000

* Specimens did not break.
† Not included in average.

Oxy-Acetylene Weld, Double V, CR VA Rod. Ratio of Oxygen to Acetylene 1.08

A6 Series—See Graph B

Stress	Specimen	Cycles for Failure
26,500	C	165,000
26,500	H	152,000
25,000	I	243,000
25,000	J	248,000
22,500	N	810,000
22,500	G	790,000
20,000	M	2,200,000
20,000	F	7,080,000
17,500	O	2,850,000
17,500	D	3,120,000
15,000	E	2,930,000
15,000	L	5,280,000
12,500*	B	40,000,000
10,000*	N	40,000,000

* Specimen did not break.

Resistance Weld

AC Series—See Graph C

Stress	Specimen	Cycles for Failure
35,000	C	259,000
32,500	B	560,000
32,500	F	728,000
30,000	H	3,100,000
30,000	N	1,330,000
30,000	M	1,900,000
27,500	G	4,850,000
27,500	D	9,900,000
27,500	L	4,250,000
26,000	O	16,100,000
26,000	P	20,800,000
25,000*	J	40,000,000
22,500*	I	40,000,000
20,000*	E	40,000,000
15,000*	Q	40,000,000
15,000*	K	40,000,000

* Specimen did not break.

Atomic Hydrogen Weld, Double V, 20 Amp. 50 V. Filler Rod 1/8" Cr. Va.

No. 3 Series—See Graph D

Stress	Cycles for Failure
25,000	1,090,000
25,000	1,076,000
22,500	1,540,000
22,500	1,590,000
20,000	1,760,000
20,000	2,150,000
20,000	1,850,000
20,000	2,070,000
17,500	4,460,000
17,500	4,200,000
15,000	5,960,000
15,000	5,340,000
12,500*	40,000,000
12,500*	40,000,000

* Specimen did not break.

Note—Five specimens were eliminated from this group because of bad pits.

Flash Weld

AC Series—See Graph E

Stress	Cycles for Failure
31,000	598,420
30,000	889,000
30,000	1,520,000
29,000	2,040,000
29,000	2,519,000
27,000	5,620,000
27,000	12,820,000
25,000*	40,000,000
25,000*	40,000,000
23,000*	40,000,000
23,000*	40,000,000

* Specimen did not break.

Note—Two specimens in the group were bent in machining. Entire group were free from pits and hard spots.

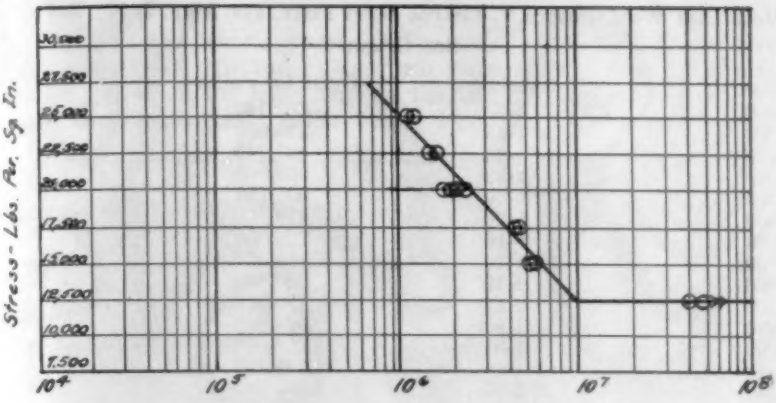
Metal Arc Weld, Single V. 200 Amp. Using 1/8" Low Carbon Rod (2 layers)

W1 Series—See Graph F

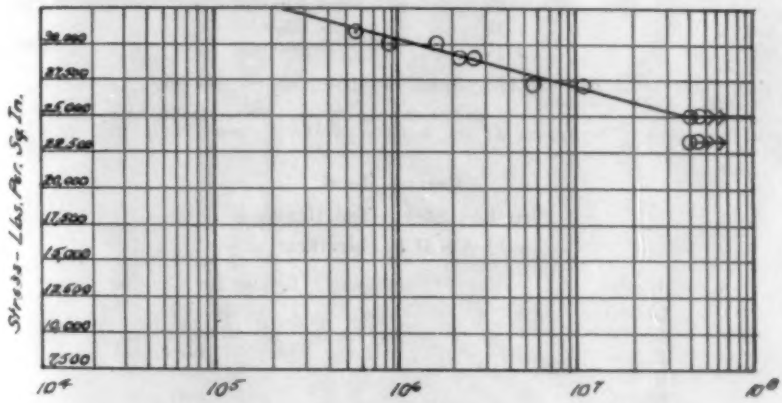
Stress	Specimen	Cycles for Failure
25,000	A	80,200
22,500	I	1,400,000
22,500	C	1,000,000
21,500	D	2,050,000
20,000	H	9,200,000
20,000	B	8,400,000
17,500*	E	40,001,700
15,000*	G	100,000,000
12,500*	F	100,000,000

* Specimen did not break.

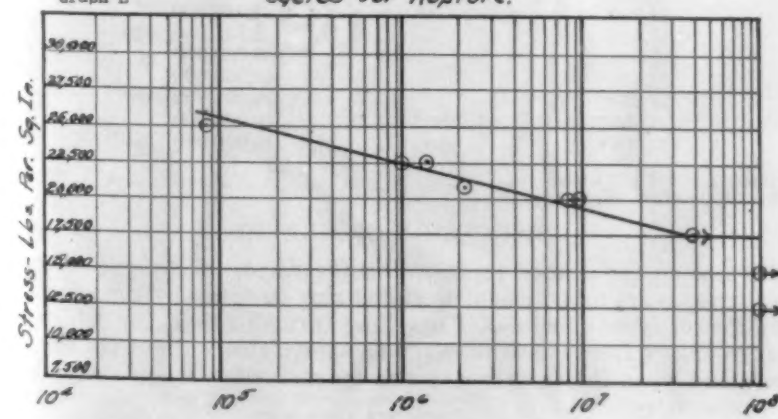
Note—Welds were made by an old experienced welder with the knowledge that his work was to be tested. Method of procedure was left to welder.



Graph D Cycles for Rupture



Graph E Cycles for Rupture.



Graph F Cycles for Rupture

Metal Arc Weld, Double V, Lukens Steel Plate, 210 Amp. 3/16" Rod (F)

See Graph G

Stress	Specimen	Cycle for Failure	Ave.
25,000	1-2	262,140	
25,000	1-25	324,000	293,070
20,000	1-6	407,240	
20,000	1-22	963,000	
20,000	1-26	655,750	
20,000	1-8	619,150	663,785
17,500	1-16	725,900	
17,500	1-7	1,194,000	
17,500	1-10	986,000	968,630
15,000	1-11	1,179,000	
15,000	1-9	2,094,000	
15,000	1-3	3,208,000	2,160,513
12,500	1-1	3,495,760	
12,500	1-27	3,185,200	3,340,000
10,000†	1-29	814,000	
10,000	1-20	3,958,000	
10,000	1-23	2,890,050	3,424,025
7,500*	1-18	40,000,000	
7,500*	1-17	40,000,000	40,000,000

† Badly pitted, not included in average. Probably an end section.
* Specimen did not break.

Note—Average tensile strength 60,524 lb. per sq. in. These welds were made in two layers each side. The layers at the bottom of the V were made with a 5/32 in. electrode.

Parent Metal

Fire Box Steel—See Graph H

15-20 A.S.M.E. Specification

Stress	Cycles for Failure
45,000	34,700
42,500	64,000
42,500	71,000
40,000	282,000
40,000	204,000
37,500	1,742,000
37,500‡	292,000
37,500	1,107,000
35,000	5,742,000
35,000	6,720,000
32,500*	40,000,000
32,500*	40,000,000
30,000*	40,000,000
30,000*	40,000,000

* Specimen did not break.
‡ Specimen bent.

DISCUSSION OF GRAPHS

The line in the graphs representing the results of fatigue at certain fixed stresses are by no means final and may be termed "trend lines" for the different types of welds. These lines furnish a basis for determining what to expect from vibration when no appreciable whip of the specimen occurs and when the deflection caused by such vibration of the specimen is not excessive.

The work in the metallic arc group was not as satisfactory on the

whole as were the other groups. In the metallic arc welded specimens a larger number of pits and oxide spots were present than in the other types of welds. Some specimens in the metallic arc welded group ran high in endurance limit, while others ran very low. Those specimens

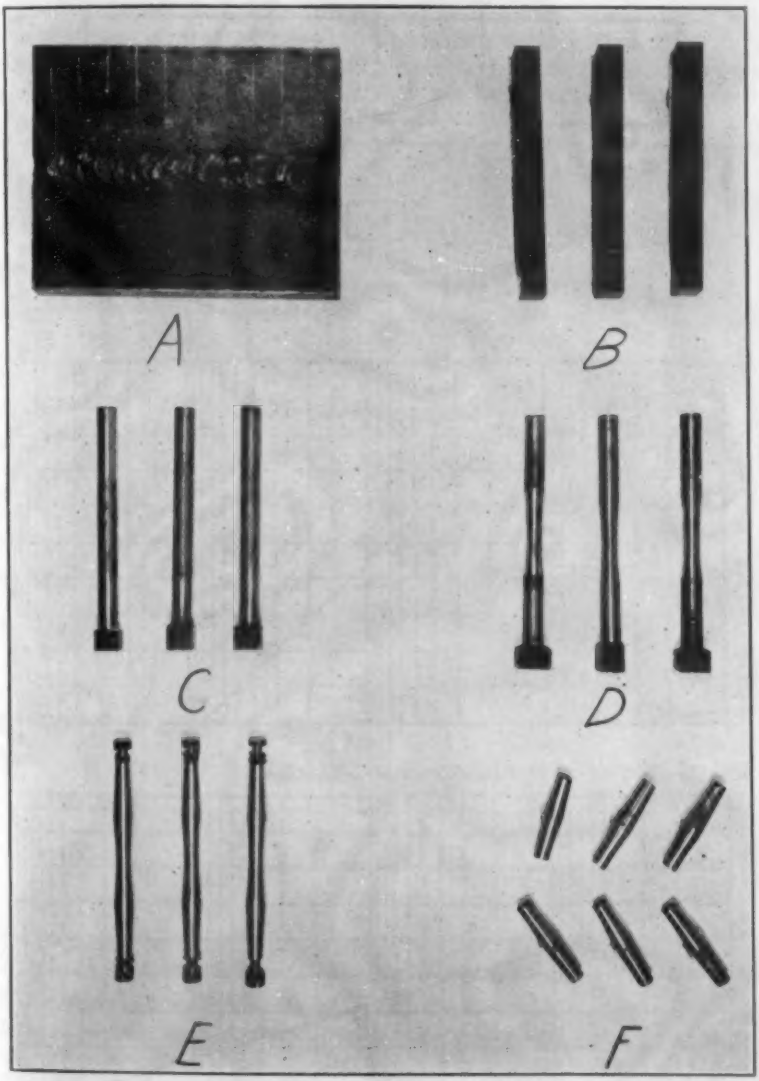


FIG. 6—PROGRESSIVE STAGES IN PREPARATION OF SPECIMENS FROM WELDED COUPONS USED IN FATIGUE TESTS

A. Coupon as received from manufacturing company
B. ¾-in. square bars sawed from coupons
C. ¾-in. square bars turned to ½ in.
D. Center section of ¼-in. specimen reduced
E. Specimen polished, tapered at ends and tapped for ¼-in. cap screw
F. Specimen after being broken in test machines

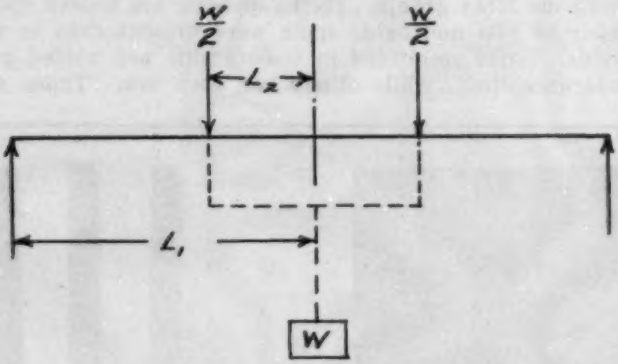
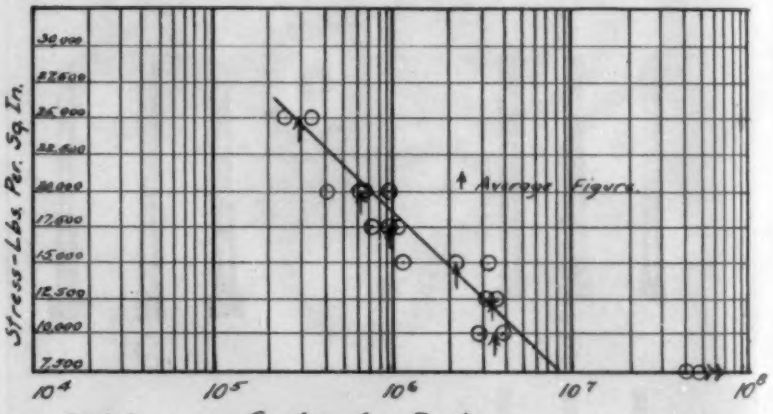
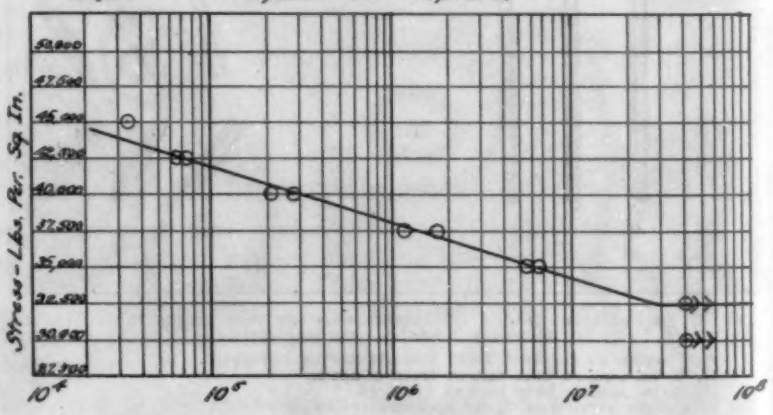


FIG. 7—POSITION OF LOADS AND DIAGRAMMATIC SKETCH FOR DETERMINING STRESSES



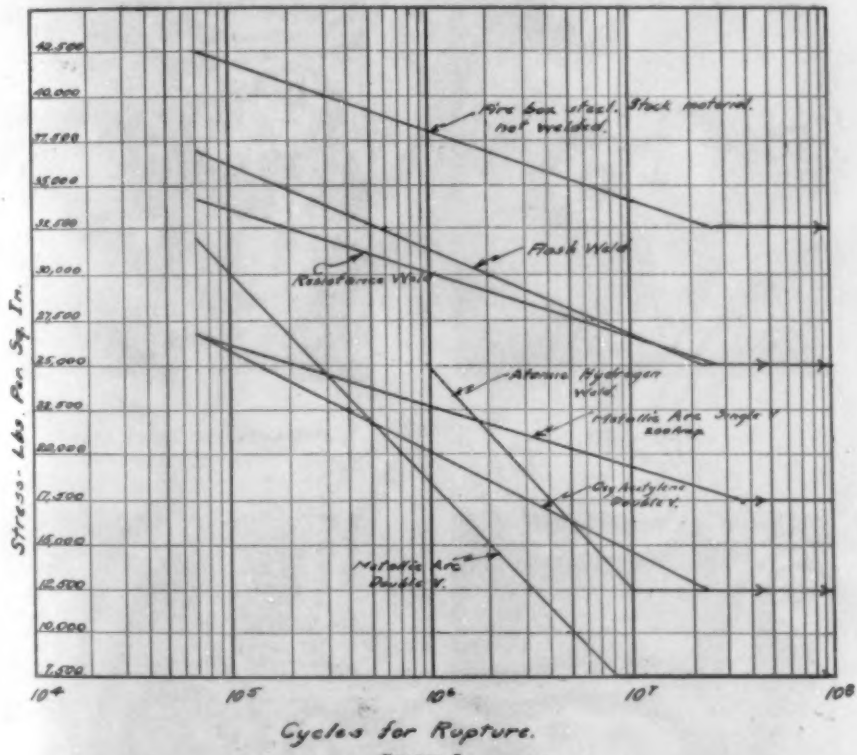
Graph G



Graph H

which showed pitting on the finished surface were excluded when making up the graphs.

An attempt was made to secure a metallic arc welded specimen from an experienced welder with the knowledge that his welds were to be used in securing test data. The result of fatigue test of this series of samples is shown in Graph F. It is interesting to note that the welder, when left to his own method of procedure used 200 amp. with a ⅛ inch low carbon rod, employing a short arc. This method, while producing a strong weld as far as fatigue is concerned may not be an economical method of



GRAPH I

making a commercial weld because of the time involved. The penetration in this weld was excellent and the deposited metal very uniform.

The resistance and flash welds gave high values for resisting undue fatigue as shown by Graphs C and E, page 52 and 55 respectively. This is explained by the fact that the welds were free from pits, and oxide spots. This is due to the process of making a butt weld. The arc produced in the welding operation excludes the formation of oxides and the formation of pockets from included gases. The welded metal is necessarily the same as the parent metal since no electrode or filter rod is used. A comparison between the welded metal and parent metal is well

illustrated by comparing the micrographs, Fig. 11, page 63. The light vertical streak through the central part of the upper micrographs shows the weld area. In this welded specimen this area is confined to a disc about 1/50 of an inch in thickness standing perpendicular to axis of specimen. There is a difference, however, in the hardness of the metal in the light streak representing the welded metal in comparison with that of the parent metal. This difference in hardness averaged about 20 points higher on the Rockwell B scale in the weld area than in the

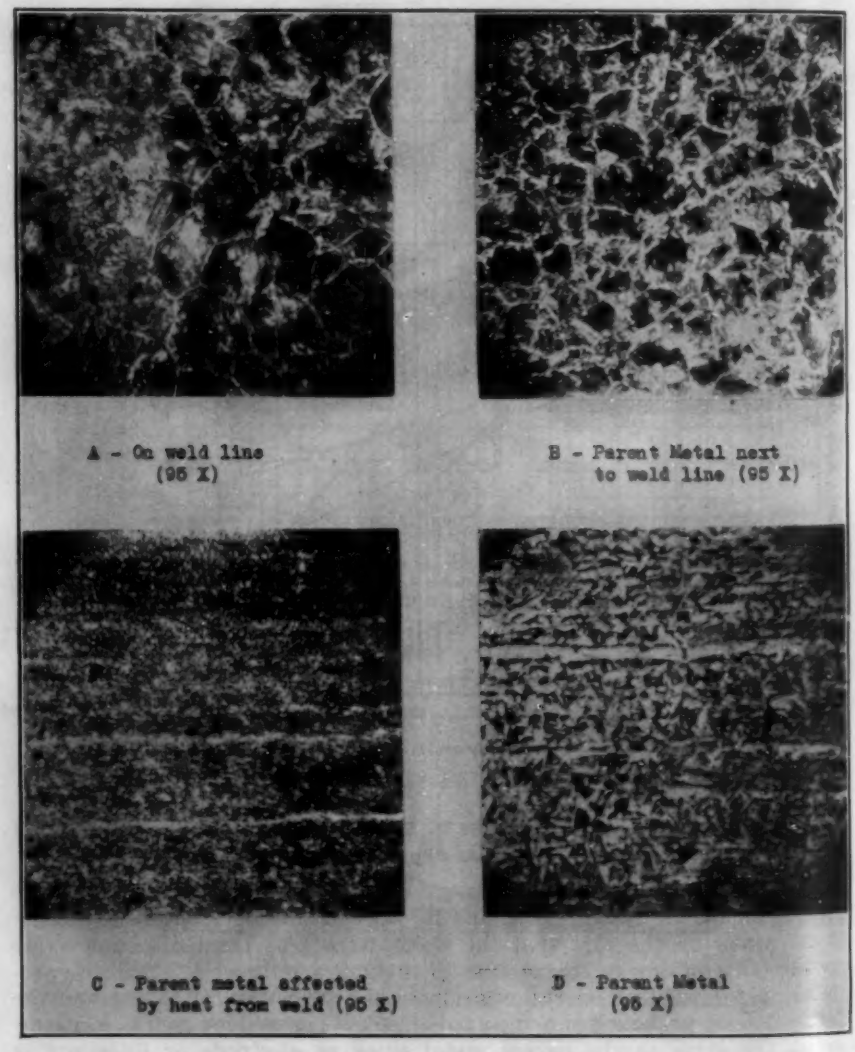


FIG. 8—METAL ARC WELD IN BETHLEHEM STEEL (C .16 PER CENT, MN .49 PER CENT) USING A $\frac{1}{8}$-IN. ELECTRODE WITH A CURRENT OF 195 AMP.

parent metal for the 15-25 Fire Box Steel. In the high carbon steels, butt welded, there was noted a difference of 165 points on the Brinell Scale between the weld area and the parent metal. The weld area was much the harder of the two.

The trend line in Graph D, page 55, for atomic hydrogen is close to the average of 3 samples presented and is not complete. This type of weld

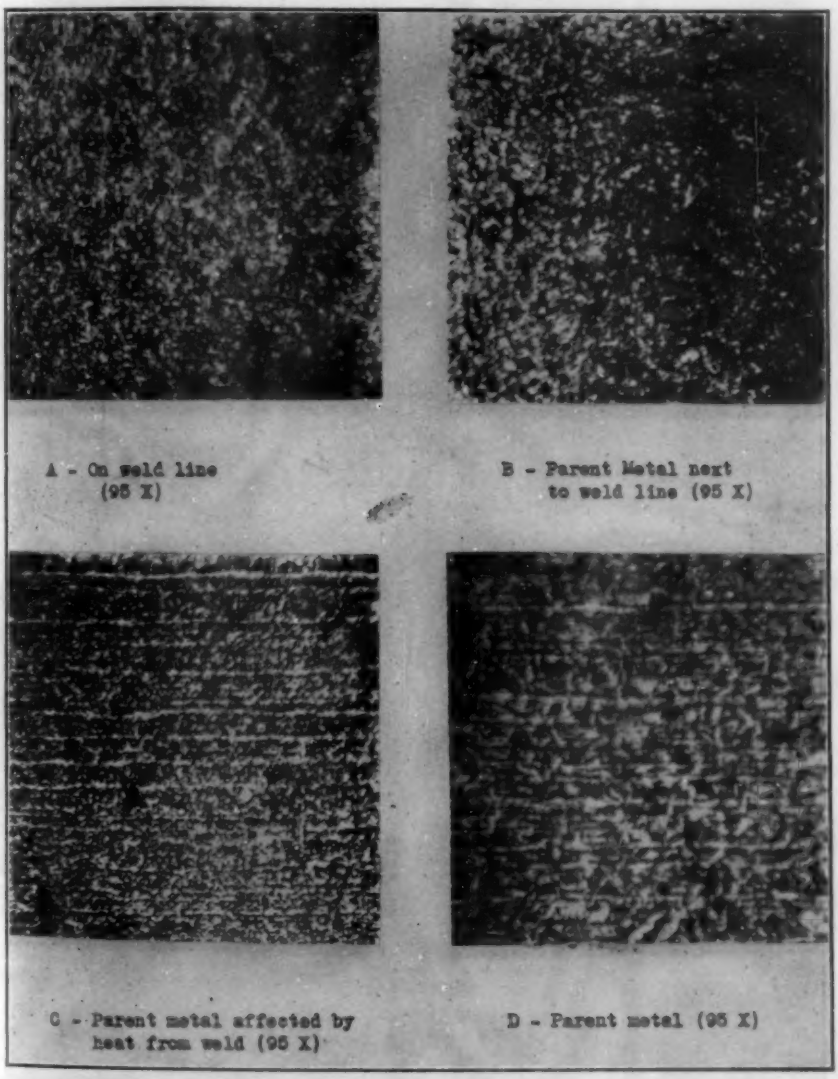


FIG. 9—ATOMIC HYDROGEN WELD IN BETHLEHEM STEEL (C .16 PER CENT, MN .49 PER CENT) USING $\frac{1}{16}$-IN. LOW CARBON ROD WITH $\frac{1}{8}$-IN. TUNGSTEN ELECTRODES WITH A CURRENT OF 55 AMP.

seems to have a higher endurance limit for the higher stresses than do either the metal arc or acetylene welding. This, however, remains to be shown by a further series of tests.

Graph I, page 59, shows the entire group of trend lines plotted to the same scale and gives a general idea of the amount of stress which each group has stood in comparison to that of the fire box steel (unwelded) which is shown as the top line of the graph.

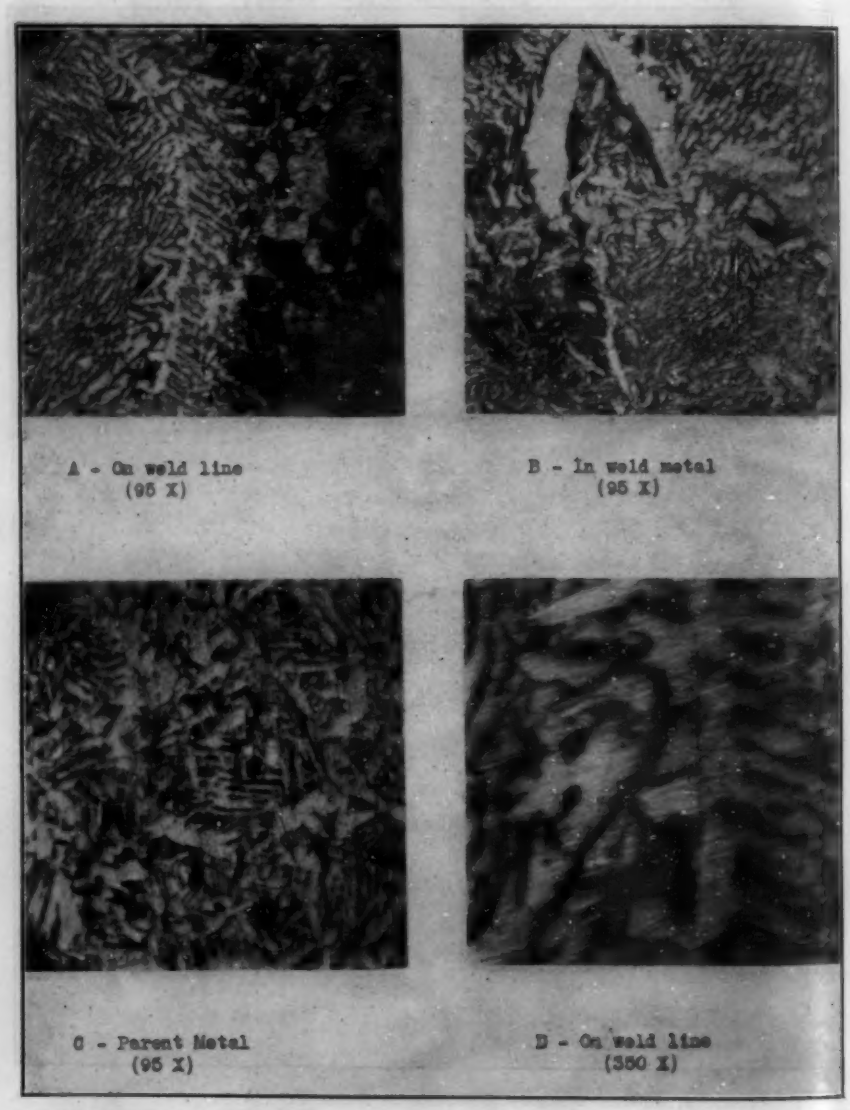


FIG. 10—OXY-ACETYLENE WELD IN BOILER PLATE USING VANADIUM WELDING ROD WITH AN OXYGEN TO ACETYLENE RATIO OF 1

The flash weld and resistance welds have approached the nearest to the endurance limit of the fire box steel unwelded. If the welds had been heat treated to give uniform hardness and grain structure, in all probability they would have equalled the original metal in endurance limit.

DISCUSSION OF MICROGRAPHS

The micrographs of the different types of welds were made at 95X. All specimens were etched in a solution of 10 per cent nitric acid to 90

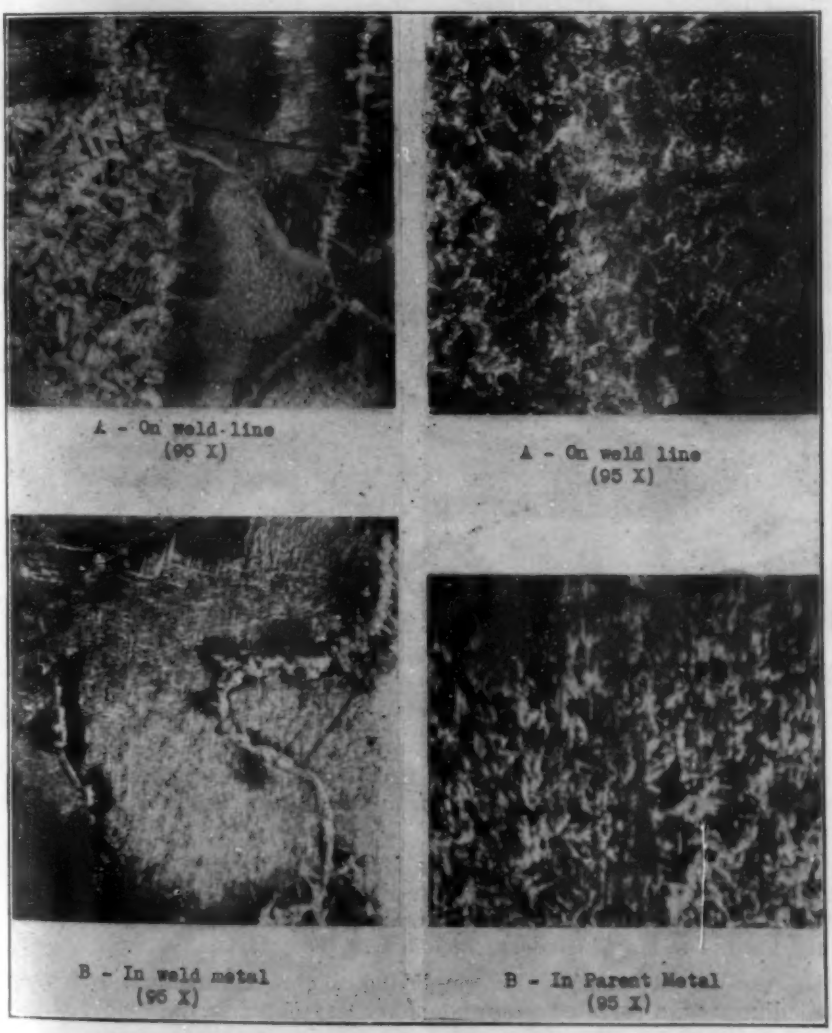


FIG. 12 — OXY-ACETYLENE WELD IN BOILER PLATE USING CHROME-VANADIUM WELDING ROD WITH AN OXYGEN TO ACETYLENE RATIO OF 1.08

FIG. 11—FLASH WELD USING ¾-IN. COLD ROLLED STOCK

per cent grain alcohol. The etching of the welded metal required a longer period than did the parent metal.

The micrographs show clearly that there are four areas in the welded region which are distinctly different, considering them from the standpoint of grain size. Fig. 8, page 60, shows these four areas: A—The deposited metal at the weld line, B—The parent metal just outside the weld line, C—The parent metal to which has been given a very fine grain structure due to the heat from the weld, and D—The parent or stock metal itself.

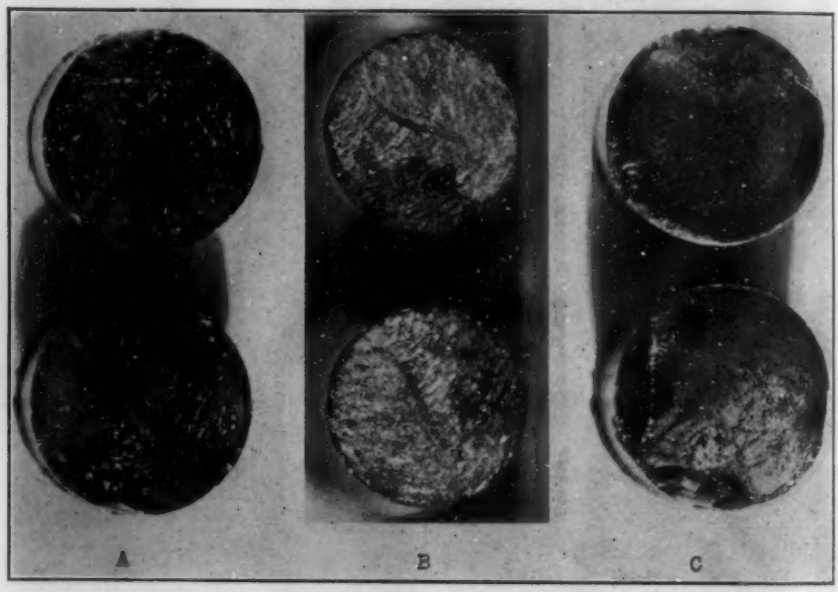


FIG. 13—TYPICAL FRACTURES OF WELDED METALS UNDER FATIGUE TESTS
A. Metallic arc weld.
B. Oxy-acetylene weld.
C. Flash weld.

The difference in grain structure in these four areas adjacent to each other has an important bearing on the endurance limit of the welded metals in fatigue.

All welded specimens present this difference in grain structure. The atomic hydrogen weld appears to give the smallest grain structure in the welded area and the oxy-acetylene welds showed the largest grain structure for the welds which were included in these tests.

In the oxy-acetylene welds employing a chrom.-vanadium rod or a vanadium rod, a serrated grain boundary was noted in the welded metal.

The grain boundary at A, Fig. 10, page 62, is typical of this metal. An enlarged picture of this type of grain boundary is shown at D in the same figure.

From observations which were made fatigue cracks at no time in any of the tests had their inception in these grain boundaries.

If the difference in grain structure between the weld metal, the parent metal adjacent to the weld, and the parent metal itself could be made uniform in size, in all probability the endurance limit of the weld would be increased. This remains to be shown in further experiments with welded metals in fatigue.

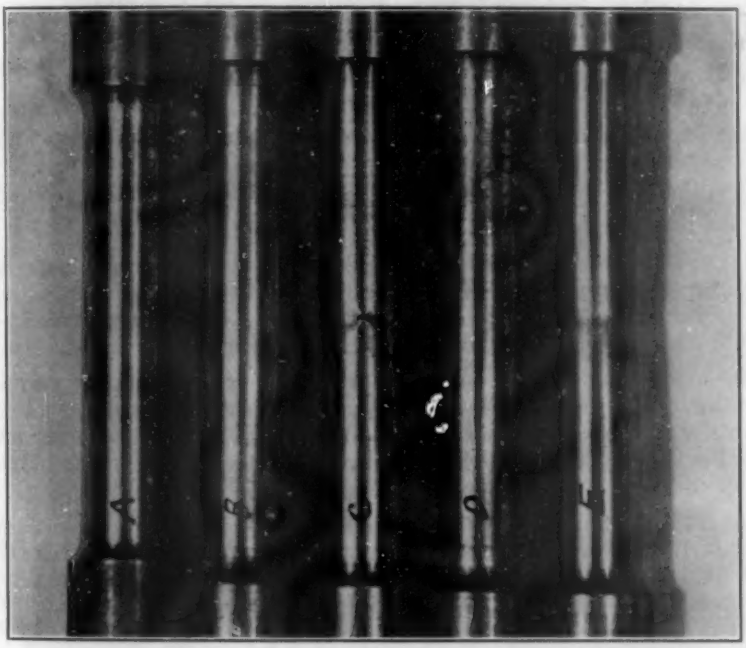


FIG. 14—TYPICAL FRACTURES OF WELDED SPECIMENS UNDER TENSION TESTS
A. Specimen not tested.
B. Flash welded specimen.
C. Metallic arc welded specimen.
D. Resistance welded specimen.
E. Oxy-acetylene welded specimen.

Figs. 13 and 14 represent typical fractures of specimens when subjected to fatigue and tension tests.

From Fig. 13 it appears as though the point of weakness was in the bottom of the V. At the bottom of the V in many ruptured specimens the surface seemed worn smooth by a scrubbing action of two surfaces against each other.

The single V metallic arc weld and the single V oxy-acetylene weld appear much stronger in fatigue than does the double V weld. In the single V weld the bottom of the V has been removed in machining the specimen from the welded coupon. In a field weld, whether it is a single V or double V weld, this condition is liable to exist.

It is yet to be determined if this failure at the center of the weld has been due to poor penetration or if the metal has in some way been weakened at this point in the welding operation.

The surfaces which are worn smooth by the scrubbing action appear to follow the plane of the scarf before the welding was begun.

CONCLUSIONS

It is at once apparent that welded specimens made from fire box steel do not equal the endurance limit of that material unwelded. The three main reasons for such are:

1. Non-homogeneous structure due to oxide spots and pits caused from gas inclusions.
2. Difference in grain structure between the metal in the weld and the metal in the original bar.
3. Difference in hardness between the metal in the weld and the metal in the original bar.

The first mentioned reason is probably the most important in bringing on fatigue. The presence of the small holes in the metal is not so harmful as usually supposed unless present in such large numbers as to materially reduce the area of the cross section of the piece.

The oxide spots and pits caused from gas inclusions during the welding operations can never be overcome by treating the weld and calls for further study along the lines of shielding the arc by gases or other means in order to eliminate this objection and increase the endurance limit of welded steels.

The last two reasons mentioned for bringing on undue fatigue, namely, grain structure, and hardness may be overcome by proper heat treatment. Such treatment is possible in a limited number of shop welded articles, but from a commercial standpoint will probably never be economical with welds in the field.

The heat treatment of the weld will also help to eliminate the locked up stresses in the bar which have occurred in the welding operation. In certain cases these stresses have been determined as high as 25,000 to 35,000 lb. per sq. in. When we consider these stresses in conjunction with the bending action of the metal in the rotating beam in which we have present the forces in tension in compression, and in shear, it is at once evident that the determination of stresses in untreated commercial welds can never be determined accurately.

This study will be continued with tests on the different types of shielded metallic arc welds and on specimens of all types of welds which have been uniformly heat treated.

Symposium on Standard Tests for Welds

Introduction and Suggested Revision of ABW Bulletin No. 1

By

American Bureau of Welding Committee on Standard Tests for Welds

TESTS for welds are made for several purposes such for example, as determining qualifications of welders, comparing welding processes or methods and comparing welding electrodes or welding rods. Obviously, standardization of the procedure in a test made for such purposes is essential if reliable conclusions are to be obtained. Standard tests for welds are desirable for other reasons: (a) they indicate to users of welding, who are not familiar with the development of the art, what tests are considered valuable at the present time in evaluating a weld; (b) they make all results reported to the industry strictly comparable; and (c) they increase the reliability of such unit values for design purposes as may properly be deduced from the test results.

In June, 1921, the American Bureau of Welding issued Bulletin No. 1, entitled "Standard Tests for Welds." Experience and the advancement of the art since that time have shown a need for revision of these standards. A suggested revision has been prepared by the Committee on Standard Tests of the American Bureau of Welding in which only three standard tests are proposed, namely, tension, bending and shear. Impact tests and fatigue tests are desirable for complete information in regard to the mechanical properties of a weld but it is doubtful if suitable techniques for these tests have yet been developed to the point where standard procedures can be proposed.

While three standard tests are proposed by the committee, there is a lack of uniformity of opinion both in the committee and outside of the committee as to the value of certain of these tests and the correctness of some of the details of the procedures proposed. The following are some of the controversial points:

(a) Is the standard ASTM tension test specimen for plate material (Parallel side specimen, 8 inch gage length) the most suitable for tension tests of welds? This specimen was, of course, developed for homogeneous material and the question arises whether it is the most satisfactory shape for a specimen which contains a discontinuity.

If the weld is weaker than the base metal then the standard ASTM specimen gives true maximum tension stress values,—that is, unit values which are directly applicable to welds in structural members which are under pure tension and in which the stresses are continuous and uniform. It would also seem that a specimen of this shape is entirely satisfactory for qualification tests of welders.

If, however, the purpose of the test is the comparison of welding wires or other variables and strengths are obtained which are higher than that of the

base metal (that is, failure occurs outside of the weld) an incomplete answer is obtained because it is not sufficient to simply show that the strength of the weld is higher than that of the base metal. It is, of course, desirable to know how much stronger it may be than the base metal in order to have a complete comparison. It would therefore seem logical to have a specimen with a much shorter reduced section, that is, so short that failure is forced to occur in the weld. But then we encounter the well known effect of nonuniform stress along the length of the specimen. This effect at the fillets extends into the reduced section resulting in breaking stresses which are too high by an uncertain amount. They are too optimistic, therefore unreliable for use in designing structural members with continuous and uniform stresses.

It might be argued that for certain strictly comparison purposes the results from such specimens would be strictly comparable just the same but this is also open to question because of the influence of the ductility of the weld itself on this stress concentration effect.

It could be suggested that the standard ASTM specimen could be used for high strength welds by using higher strength base metal. Then we have the question of the influence of the base metal on the fusion zone of the weld.

Another question that has been raised is the value of a tension test on a specimen composed wholly of weld metal and prepared in the manner indicated in the proposed standard. It is contended that weld metal deposited according to that procedure is not necessarily the same as that deposited in a weld because of the influence of the base metal.

(b) The so-called ductility of a weld is one of the most important of the mechanical properties. It is, however, very difficult to determine by any of the usual methods because of the discontinuity along a specimen containing a weld. The ordinary method of measuring ductility by means of elongation measurements on a tension test specimen is not very satisfactory. Simple bending tests have been used to give some information on this property. Such a test is attractive because of its simplicity and its direct appeal to the construction man. However, the objection has been that it is just a rough test from which reliable unit values cannot be obtained.

The bending test suggested in these standards is that proposed by W. B. Miller (Journal AWS, September, 1927) and in it, it is attempted to overcome this objection. In other words, approximate ductility values are obtained from measurements of elongation of the outer fibers in the bent specimen when rupture occurs. However, there has been some question as to whether this test is reliable for various kinds of welds, different thicknesses of materials, etc. In other words, it has been questioned whether the method is suitable as a general standard for ordinary industrial testing.

(c) The shear test proposed has been used to some extent with considerable satisfaction. Extensive experience has not yet been had and the particular procedure prescribed is rather expensive because of the large size of specimen. It has been contended that a shear test for welds is a highly desirable one but if the test is to be generally useful the specimen should be a smaller one. There is, however, the question as to how small a specimen can be used and yet obtain true shear values.

It thus would seem that there are a number of open questions in regard to these proposed standards. Furthermore, opinion is not unanimous that tentative standard impact and fatigue tests should not be proposed at this time.

It is, of course, obvious that if standards of this sort are to be accepted and used in the industry, there must be general agreement as to their desirability and value. In order to get more discussion of some of these controversial matters, the Meetings and Papers Committee has arranged for this symposium centered around the suggested standards, which are appended hereto. It is expected that there will be presented by various specialists in this particular field of the welding industry experimental

and other evidence bearing on these questions. It is hoped that their contributions and the ensuing discussion will make it feasible for the committee to agree on standards which will be reasonably satisfactory to all concerned and which can therefore be recommended to the American Bureau of Welding for at least tentative adoption.

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Suggested Revision of ABW Bulletin No. 1* Standard Tests for Welds

FOREWORD

The primary purpose of this bulletin is to provide standardized procedures for the various mechanical tests which are made in connection with welds (tests of base metal, weld metal, and sample welds, etc.) so that results of such tests will be comparable and any unit values properly deducible therefrom will be as reliable as possible. Only those tests and measurements have been included which the Committee considers of most value in the evaluation of welds.

Tests of welds may be made for any one of several purposes,—qualification of operators, comparison of welding electrodes and rods, comparison of welding methods and similar purposes, design data, etc. Standards for tests of sample welds as *welds* should be distinguished from tests of sample welded joints as *joints*. In the former, a standard sample weld and standard test specimen therefrom can be prescribed but in the latter this is obviously not feasible because the design of the joint determines how a suitable test joint shall be prepared. The standards herein have been prepared primarily for tests of sample welds but it is recommended that in the testing of sample joints, the procedures prescribed be used insofar as it is practicable to do so in order that all test results in connection with welds will be comparable as feasible.

Satisfactory tests for welds in structures have not yet been developed. Such tests must necessarily be non-destructive and while much attention is being given to this need of the industry and some progress is being made, the problem is a difficult one and the final solution is not yet in sight.

It is recognized that for many purposes, a simpler procedure in a given test than that prescribed herein may be quite sufficient. It is recommended that in such cases the desired simplification be obtained by omission of observations and calculations that are not desired but that those that are made be carried out in accordance with the procedure prescribed.

*Proposed at this time for discussion only. It is hoped by the Committee the discussion will enable them to recommend an acceptable revision.

Preparation of Samples and Test Specimens

It is recommended that sample welds (for determining the proficiency of operators, comparing welding electrodes or welding wires, etc.) be prepared from base metal in plate form, and if the edges are to be beveled

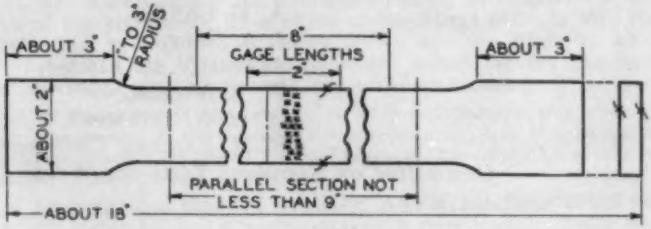
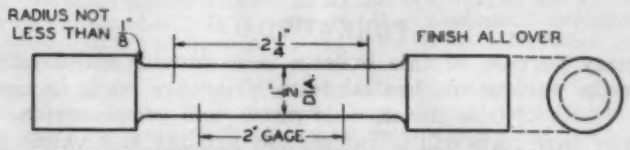


FIG 1



THE GAGE LENGTHS, PARALLEL PORTIONS AND FILLETS SHALL BE AS SHOWN, BUT THE ENDS MAY BE OF ANY FORM WHICH WILL FIT THE HOLDERS OF THE TESTING MACHINE

FIG. 2

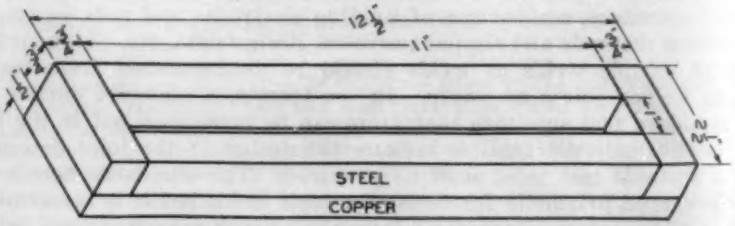


FIG. 3

(as is usually done with material over ¼-in. thick), that single V, 45-degree bevels be used.

It is obviously not practicable to prescribe standard dimensions of the sample weld as these will depend upon the purpose of the tests and the number of tests to be made. Each sample weld should be of sufficient size to permit the preparation therefrom of all the test specimens prescribed herein for each of the different kinds of tests to be made. The sample weld should preferably be so made that the longest axes of the test specimens cut from it are parallel to the direction of rolling.

General Instructions

Wherever applicable, the standard procedure of the American Society for Testing Materials as given in "Tentative Methods of Tension Testing of Metallic Materials" (E8-27T) shall be followed.

Three duplicate specimens shall be tested in any one test and the average taken as the value of the property determined by that test.

Tension Tests, Base Metal

Test Specimens. The shape and dimensions of the test specimen for sheet or plate base metal are shown in Fig. 1. It is to be noted that a thickness in excess of ¾-in. will require a testing machine of 100,000 lb. capacity in the case of ordinary steel. If the specimen is cut from regular commercial sheet or plate material, it is usually not necessary to machine the 1.5 in. faces of the specimen.

The shape and dimensions of the test specimen for cast base metal is shown in Fig. 2*. It is particularly important to use swivel specimen holders when testing such specimens in order to entirely eliminate undesirable stresses.

Results to be Recorded. The following data are to be recorded in connection with tension tests of base metal:

(a) Ultimate Strength. Stress (lb. per sq. in.) computed from the area of the original section.

(b) Yield Point. Stress (lb. per sq. in.) at which marked increase in deformation of the specimen occurs without increase of load as indicated by a sudden dropping of the beam of the testing machine or by a sudden increase of the rate of elongation as shown by dividers.

(c) Reduction of Area. Expressed in per cent of the original area.

(d) Appearance of Fracture. The general appearance of the fracture should be recorded, i.e. crystalline, fibrous, silky, etc.

The following data are optional:

(e) Proportional Limit. Stress (lb. per sq. in.) at which the deformation ceases to be directly proportional to the load.

Any type of extensometer may be used which measures the deformations of two opposite elements of the specimen, preferably on the edges. Deformation measurements on only one element of the specimen may be subject to large error even when the gage marks are on the center line of the 1.5-inch side.

The gage length may be either 2 or 8 inches.

(f) Modulus of Elasticity. Stress (lb. per sq. in.) computed from data obtained from a specimen having an 8-inch gage length; measurements to be taken on two opposite elements, one on each edge of the specimen.

(g) Total Elongation. Gage marks should be laid off every inch along a line at the center of one of the 1.5-inch faces of the specimen before placing in the testing machine and the total elongation in every inch after rupture recorded. The total elongation in the 1-inch, 2-inch and 8-inch (if any) length which included the break should be reported.

Tension Tests, Weld Metal

Test Specimens. The shape and dimensions of the test specimen are shown in Fig. 2. It shall be prepared from a bar of weld metal, ¾ by 1 by 11 in. This bar shall be formed entirely by depositing filling metal in an open box of the shape shown in Fig. 3 employing exactly the same method used in making the corresponding test weld. For metal electrodes this box shall consist of a copper plate ½-in. thick, upon which is secured a frame of steel bars, ¾-in. square. The parts of the box are secured

*A diameter of 0.505-inch may be used if desired. This gives an area of exactly 0.200 square inch.

in any convenient manner. The copper plate, during this operation shall rest upon a steel plate. After the bar is formed, the copper plate and the frame may be removed by any suitable machining operation.

For gas welding, the copper plate should be replaced by a steel plate. For thermit, a box of suitable refractory material should be used.

Results to be Recorded. The data to be recorded in connection with tension tests of weld metal shall be the same as for base metal except those involving an 8-in. length. If, however, the modulus of elasticity is desired, a specimen similar to that shown in Fig. 2 with a gage length of 8 in. shall be employed.

Tension Tests, Welds

Test Specimens. The shape and dimensions of the test specimen are shown in Fig. 1 with the weld at the center. If the material is cast or brittle, the specimen shown in Fig. 2 shall be used with the weld located at the center.

It is especially necessary that the 1.5-in. sides of Fig. 1 specimens be machined, particularly if the two pieces of base metal are offset or if they form an angle at the weld. Tests made in the latter case, where the specimens are not machined, are not reliable. Furthermore, care must be taken that specimens having the latter defects are not "straightened" before being machined because such treatment is likely to materially de-

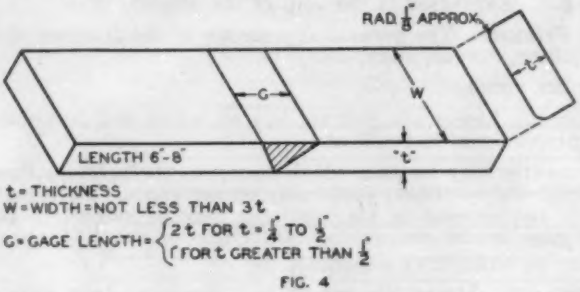


FIG. 4

FIG. 7

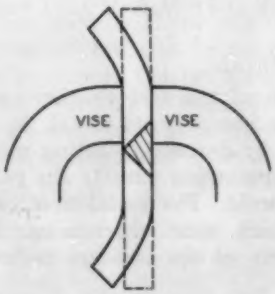


FIG. 5

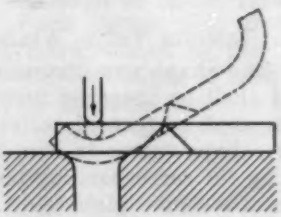


FIG. 6

FIG. 8

crease the strength of the weld. A roughing cut in a planer or shaper which will just "clean up" the surfaces of the specimen is sufficient.

Results to be Recorded. The following data are to be recorded in connection with tension tests of weld specimens:

(a) Utlimate Strength. Stress (lb. per sq. in.) computed from the area of the original section.

(b) Appearance of Fracture. The appearance of the fracture as determined with the aid of a low-power magnifying glass shall be recorded. The character described by the following nomenclature should be covered indicating as far as possible the per cent of the total area which is involved. For example, "10 per cent not welded" would signify that approximately 10 per cent of the total area of cross section at the fracture is exposed base metal—that is, not welded.

Spongy: Full of small cavities; the structure resembles that of a sponge; porous.

Slag inclusions: Foreign matter entrapped in the weld.

Gas pockets: Small or large cavities more or less isolated (i.e., not of a regular spongy structure).

Not welded: Exposure of any portion of the surface of the base metal indicating imperfect fusion between the base metal and the filling metal.

Laps: Imperfect fusion between adjacent portions or between successive layers of filling metal.

Note: No provision is made for elongation measurements of any kind. Such measurements with the usual gage lengths are of little value because of the predominating influence of the base metal. Where such data are required special provision should be made to get elongation readings over as short a distance as possible at the weld so as to include a minimum of base metal.

Bend Tests, Welds

Principle of Method. The specimen is placed as a strut in a vise or compression machine and a compression load applied at the ends until failure occurs in the outside fibers of the bent specimen. The relative evaluation of the ability of the specimen to withstand bending is measured by the elongation of the outside fiber.

Preparation of Specimen. For quantitative results rectangular specimens with widths at least *three times* the thickness should be used. The edges should be rounded off so that fracture does not take place at the edge. The outside surface should be smooth and free from local defects. The length may vary with the thickness of the piece and is unimportant provided it is long enough to allow performing the bending operation. (See Fig. 4).

Procedure. The bend in the specimen is started by holding the specimen in a vise about one-third from the end producing an initial bend at this point with hammer blows (see Fig. 5) or the specimen may be set up on cross supports and the bend started by a ram at the third point (see Fig. 6).

The specimen with the initial bend at each end is placed as a strut in a vise or compression machine and pressure applied gradually (i.e. without shock) at the ends until failure occurs in the outside fibers of the bend specimen (see Fig. 7). Speed is not a factor if there is no shock. The continuity of closing and the speed may be varied without

affecting the results within the limits of accuracy expected, i.e., ± 5 per cent of the value of the fiber elongation.

Result to be Recorded. The performance of the specimen is evaluated by measurement of the outside fiber elongation. The most direct method of doing this is to place gage marks on the specimen before bending and measure the extension directly with a flexible scale graduated to one hundredths of an inch.

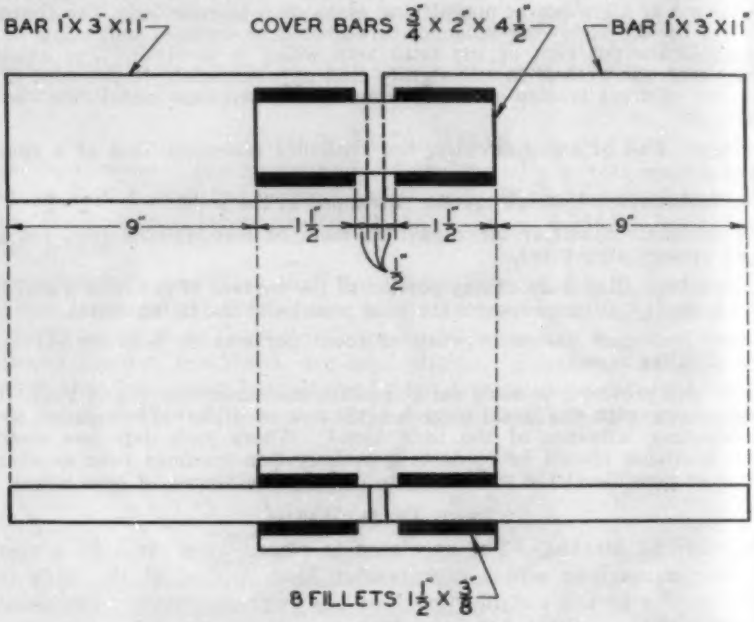


FIG. 9

Experiments have shown that for consistent results the gage length should be at least 0.3 in. and not greater than 1 in., except in plate from ¼ in. to ½ in. thick, in which case the maximum gage length should not be more than twice the thickness of the plate. With material less than ¼ in. thick, the difficulties of measurement are so great that the committee is not yet prepared to make definite recommendations.

Any other method of measuring the fiber elongation may be used, provided it gives the same values as the direct method. For example, in some cases it may be objectionable to put gagemarks on the specimen, in which instance the radius of the outside of the specimen may be measured and the per cent elongation calculated according to the formula: per cent elongation $= 100 \frac{t}{2R}$ where t = thickness and R = radius to neutral plane (see Fig 8).

Shear Tests, Fillet Welds

Preparation of Specimen. The specimen shall be prepared as shown in Fig. 9. The dimensions of the fillets are to be within the following:

legs, maximum 0.5 in., minimum 0.375 in.; throat, maximum 0.354 in., minimum, 0.265 in.*

Notes: It is essential that the stresses in the main and cover bars never exceed the elastic limit. This specimen is designed on the basis of a maximum stress of 25,000 lb. per sq. in. in the main and cover bars of ordinary bar steel.

Attention is called to the fact that the necessary pieces can be cut from standard bar stock with a torch. As no machining is involved this greatly simplifies the preparation of specimens.

Procedure. The specimen shall be tested in a tension testing machine just as it is prepared without any machining. Care shall be taken that no bending stresses are introduced. This is preferably insured by the use of swivel test heads or grips.

Results to be Recorded. The following data are to be recorded:

(a) Load at first crack and maximum load. Corresponding unit values in lb. per inch length of weld by dividing the loads by (1) 6 inches nominal or gross length of the four welds and (2) 4 inches, the net length of the four welds (arbitrarily assumed to be 1/4 inch less at each end than the nominal length).

(b) The usual details such as location of failure with respect to the specimen and with respect to the weld itself, and fractured surfaces described as prescribed for the tension tests.

*Limits prescribed in the investigation conducted by the Structural Steel Welding Committtee, American Bureau of Welding.

Bend Tests*

W. B. MILLER†

IN June, 1921 there was issued by the American Bureau of Welding Bulletin No. 1 entitled "Standard Tests for Welds." Since that time advancements in the art have indicated that certain standard tests or methods of making and evaluating them need revision. One of the tests described was the bend test. Every one is probably familiar with the bending apparatus there described. Briefly it consists of forcing the bend coupon, by means of a ram, between two anvil blocks having their edges rounded off to a 1 in. radius. The radius of curvature of the ram is required to conform to the A. S. T. M. specifications for bending tests for ship plate steel viz.:

Thickness of Plate	Radius of End of Ram	Calculated Per Cent Elongation of Outside Fibers
Up to 3/4"	0.5 × thickness	50
Over 3/4" to 1¼"	0.75 × thickness	40
Over 1¼"	1.0 × thickness	33

The total angle through which the specimen has been bent when the first crack appears on the convex surface is taken as the index of bending quality in this test.

Three years ago the writer presented before this Society a paper entitled "The Bend Test As Applied to Welded Coupons" in which it was recommended that the test be evaluated by measuring the per cent elongation in the outside fibers. Test results were presented to show

*Paper to be presented at Fall meeting of the A. W. S., Sept., 1930, Chicago.
†Metallurgist, Union Carbide & Carbon Research Labs.

that with free bending and measuring the per cent elongation of the outside fibers, quite consistent and comparative results were obtained. Although free bending in a vise or press was preferred, the way was left open for performing the bend in any manner desired provided it was evaluated in ductility terms, i.e., per cent elongation of the outside fibers.

Objections have been made to this method of bend testing on the grounds that bend test ductility is not the same as tensile ductility. Since it is so far impossible to get true tensile elongation figures, any test, such as the suggested bend method, which will give some idea of weld metal ductility, should be welcomed by the welding fraternity. It has never been represented that bend elongation and tensile elongation are the same.

Reasons for Using the Bend Test

Although it is generally agreed that the bend test is a more severe test of ductility than the tension test, no doubt many wonder what is the basis for this opinion. Let us consider two steels having practically identical tensile strength, yield point, per cent elongation in 2 in., reduction of area, but having widely different impact values, which were subjected to bend tests. It is found that marked differences in bending resulted. The differences were not as marked as in the impact test but were sufficiently great to show that the bend test measured some combination of properties not shown by the tensile test. Ease of testing and lack of elaborate equipment are further justifications for the bend test. Also the use of the bend test for so many years is indicative of its usefulness.

Status of Bend Test

The following taken from the report of the A. S. T. M. Committee on Bend Testing outlines the present status of the Bend Test.

Proposed Method of Quantitative Bend Testing: The method found to give consistent quantitative results consists essentially in bending the speciment as a strut in a vise or press. (See Fig. 7 page 72). This is followed by measurement of the elongation of the outside fibers at the point of maximum bending. This is known as free bending with measurement of fiber elongation.

Preparation of Specimens: For quantitative results in which the final figure is independent of the thickness of the specimen, rectangular specimens with widths at least three times the thickness should be used. The edges should be smoother or rounded to prevent edge fracture. The outside surface should be smooth and free from local defects. The length may vary with the thickness but is unimportant provided it is long enough to perform the bending operation. (See Fig. 4 page 72).

Method of Starting the Bend: In order to start the bend any stress or strain at the point which will have the maximum bending should be avoided. This may be accomplished by holding the specimen in a vise about one-third from the end, producing an initial bend at this point by

hammer blows, or the specimen may be set up on cross supports and the initial bend started in this way at the third point. This is performed on both ends. Fig. 5 and 6 show these methods of starting the bend.

Method of Closing the Bend: The specimen with initial bends on each end is placed in a vise or press as a strut and compression applied at the ends. The press is closed until failure of the outside fibers occurs. The speed of closing the bend is not a factor unless shock is used.

Measurement of Fiber Elongation: The most direct method of determining the fiber elongation is to place gage marks on the specimen before bending and to measure the final length directly with a flexible scale.

Experiments have shown that for consistent results the gage length should be at least 0.3 in. and not greater than 1.0 in. except in the case of plate ¼ in. to ½ in. the maximum gage length should be not more than twice the thickness. With material less than ¼ in. thick the difficulties in measurements are so great that the committee is not yet prepared to make any recommendations. Any other methods of measuring the fiber elongation that give the same values as the direct method may be used. For example, in some cases it may be objectionable to put gage marks on the specimen. In this event the radius of the outside of the specimen may be measured and the elongation calculated. (See Fig. 8 page 72).

Advantages of the Bend Test

The consistency of the results is excellent and constitutes a main advantage. For homogeneous material similar specimens of the same material not only give the same results, but the same material when tested in various thicknesses gives the same results showing that the test measures inherent properties of the metal. Any inconsistencies in results of weld tests may be due to weld irregularities rather than to any unreliability of the method.

Test Data

In substantiation of the foregoing statements the following test results are submitted:

Showing Difference in Bend without Difference in Tensile Properties

Specimen	Yield Point, Lb./Sq. In.	Ult. Str., Lb./Sq. In.	Per Cent Elong. in 2	Per Cent Red. of Area	Izod, Ft./Lb.	Bend, Per Cent
1	36,000	55,000	32	64	49	125
2	37,000	54,000	33	62	6	34

Showing Measured Ductility of Different Welds in Tension and Bending

Test No.	Elongation in 2" (Tensile), Per Cent	Bend Elong., Per Cent
1	11	19
2	6	20
3	7	30
4	5	36

Elongation in Bend Test of Bars of Two Steels of Various Dimensions

Thickness, In.	Width, In.	Per Cent Bend Elongation Material A	Material B
.25	.25	48	..
	.50	44	82
	.75	37	75
	1.00	39	74
	1.50	39	77
	2.00	37	72
.475	.50	46	..
	.75	44	80
	1.00	39	75
	1.50	38	70
	2.00	40	74
.50	.75	45	..
	1.00	43	..
	1.50	39	71
	2.00	39	74
.75	.75	46	..
	1.00	42	..
	1.50	37	..
	2.00	38	..

It will be noted that when the width is at least three times the thickness, check results are obtained on the same material.

Showing Effect of Speed of Closing Bend

	Speed	Dimensions in Inches	Elongation, Per Cent
Material A	.025 in./min.	.25 x 1.0	39
		.50 x 1.5	40
	2.0 in./min.	.25 x 1.0	37
		.50 x 1.5	38
	vise (intermittent)	.25 x 1.0	38
		.50 x 1.5	37
	Speed	**Dimensions in Inches**	**Elongation, Per Cent**
Material B	.025 in./min.	.25 x 1.0	74
		.50 x 1.5	70
	2.0 in./min.	.25 x 1.0	76
		.50 x 1.5	71
	vise (intermittent)	.25 x 1.0	74
		.50 x 1.5	73

These and other published data seem sufficient to warrant the recommendation that the bend test for welds be evaluated by measuring the per cent elongation of the outside fibers, rather than the angle of bend. Welding literature is profuse with bend test data in which the angle of bend was measured. Photographs of the bent coupons indicate clearly that in many of the coupons little, if any, elongation took place in the outside fibers of the weld metal. The measurement of the extension of the outside fiber elongation is rational and leaves no doubt in the writer's mind as to the effect of the bending on the weld metal.

Tensile Tests for Welds*

By James W. Owens†

THE Committee on Standard Tests for Welds has indicated some of the controversial points on the two standard A.S.T.M. tensile test specimens now used for fusion butt welds, viz.—the specimen for plate material with parallel sides and an 8-inch gage length, and the 0.505-inch diameter specimen with a 2-inch gage length for cast material. These specimens are shown in Figs. 1 and 2 respectively of the Committee's suggested revision of the American Bureau of Welding, Bulletin No. 1.

In considering the question, it is essential to remember that:—

(a) The *weld as a "joint"* is made up of three variables—the *weld metal*, the *base metal*, and the junction between the weld and base metals known as the *fusion zone*. Any evaluation of the weld as a joint should therefore separately determine the properties of each of these variables.

(b) The ideal weld is one in which the physical, chemical, and metallurgical characteristics of the weld metal and fusion zones are identical or better with those of the base metal.

(c) The base metal is the standard for comparing the properties of welds.

(d) Weld metal is in general of two types—*First*, "brittle" metal, or metal having low ductility and a tensile strength approximately the same as the base metal; and *Second*, "tough" metal, or metal having good ductility and a tensile strength equal to or better than that of the base metal. For brevity the terms "brittle" and "tough" will be used in referring to these two general types of weld metal.

It is also essential to remember that in the development of standard tension tests for welds, we must consider:

(a) Test specimens for evaluating a welding process by the properties of the welds produced by the process.

(b) Test specimens for testing the qualification of welders using a specific process.

(c) Test specimens for determining the properties of the welds actually used in a structure, for example a pressure vessel.

In view of the foregoing the subject will be considered under the following headings:

A. Tension Tests for the Weld Metal.
B. Tension Tests for the Base Metal.
C. Tension Tests of the Fusion Zone and for the Weld as a Joint.

*Paper to be presented at Symposium, "Testing of Welds," at Fall Meeting, A.W.S., Chicago, September, 1930.

†Engineering Director, Welding Engineering & Research Corp., New York.

Tension Tests for the Weld Metal.

The properties of the weld metal obtainable by a tension specimen can best be secured by the use of specimens consisting entirely of weld metal. If the test is to determine the properties of the weld produced by a welding process, or the properties of welds actually used in a structure, the specimen should be removed longitudinally out of the weld metal of sample welds. This type of specimen is usually not necessary for qualifying tests of welders unless they will be called upon to weld material of appreciable thickness.

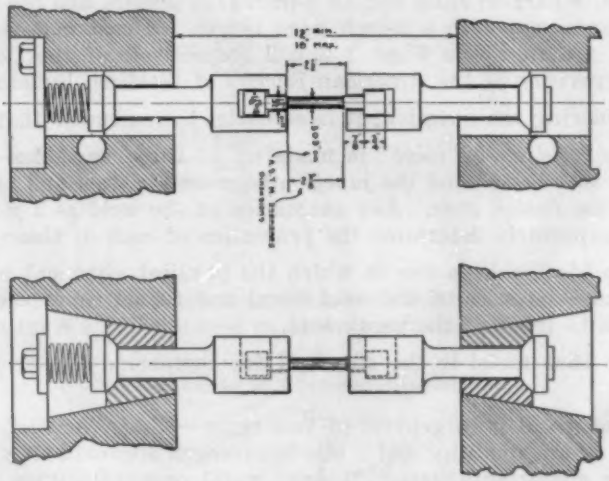


FIG. 1—TYPE SWIVEL HOLDER FOR ROUND WELD AND BASE METAL SPECIMENS (Courtesy Southwark Foundry & Machine Co., Philadelphia, Pa.)

As it is in general impractical and very expensive to prepare weld metal specimens similar to the A.S.T.M. standard specimen for plate material, the writer would strongly recommend the adoption of the A.S.T.M. 0.505-inch diameter specimen as the standard for determining the physical properties of the weld metal. Furthermore, as it will be necessary to test welds less than ½ inch thick, it will not always be possible to adhere to a specimen having a diameter of 0.505 inch, therefore, he would also recommend that the Welding Society's standard permit the use of specimens of any diameter provided the gage length of the specimen is four times the diameter of the specimen.

This recommendation on ratio of gage length to specimen diameter is based on tests made by Dr. T. McLean Jasper, Research Director of the A. O. Smith Corp., wherein it was determined that the percent elongation of the metal obtained with specimens of different diameters is only comparable when this ratio is adhered to.

By the use of this specimen we can obtain values for the weld metal of ultimate stress, yield point, percent elongation, and reduction in area. This specimen also gives a good indication of the degree of porosity.

Tension Tests for the Base Metal.

It is a well recognized fact that the properties of the base metal influence the properties of the weld, therefore, a standard requirement for tension tests for welds should be that the base metal used in the preparation of specimens should have the same properties as that used in the structure or class of work for which the tests are made.

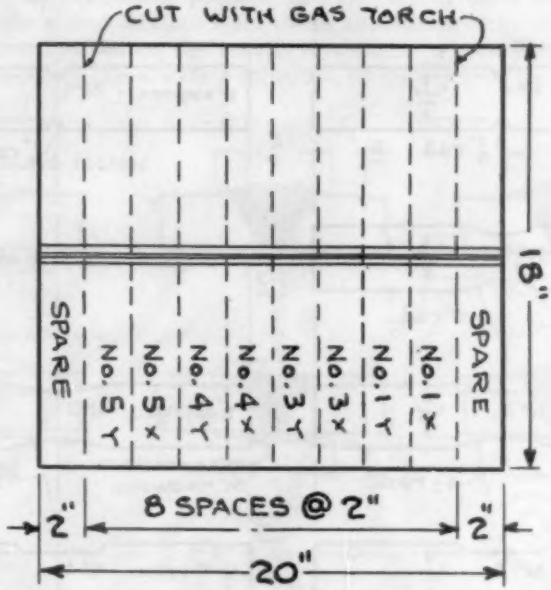


FIG. 2—TEST PLATE USED TO DETERMINE THE EFFECT OF SHAPE OF SPECIMEN ON TEST VALUES SECURED IN TENSION

The A.S.T.M. specimen for plate material, with parallel sides, and an 8-inch gage length, has in the past been used exclusively for determining the properties of plate material, and the A.S.T.M. 0.505-inch diameter specimen with a 2-inch gage length has been used exclusively for determining the properties of cast material. As the base metal is the standard for comparing the properties of the weld, it would seem desirable to use the same type of tension specimen for the base metal as was used for the weld metal.

In view of this, it is recommended that the round specimen with the suggested ratio of gage length to diameter of specimen, recommended under "Tension Tests for Welds," be also used for determining the tension properties of the base metal.

Tension Tests for the Fusion Zone and the Weld as a Joint.

Having, by the tests previously specified, obtained information on the tension properties of the weld and base metals, the primary object of any test of the weld as a joint would be to determine the effectiveness of the bond of these metals in the fusion zone. This information can

therefore best be secured by the removal of a specimen transverse to the joint and containing the three variables—the base metal, the weld metal, and the fusion zone.

Influence of Brittle and Tough Weld Metal.

When using the standard A.S.T.M. specimen with parallel sides and an 8-inch gage length, the writer has found that if the weld metal is "brittle" such a specimen will show whether good fusion has been secured, and

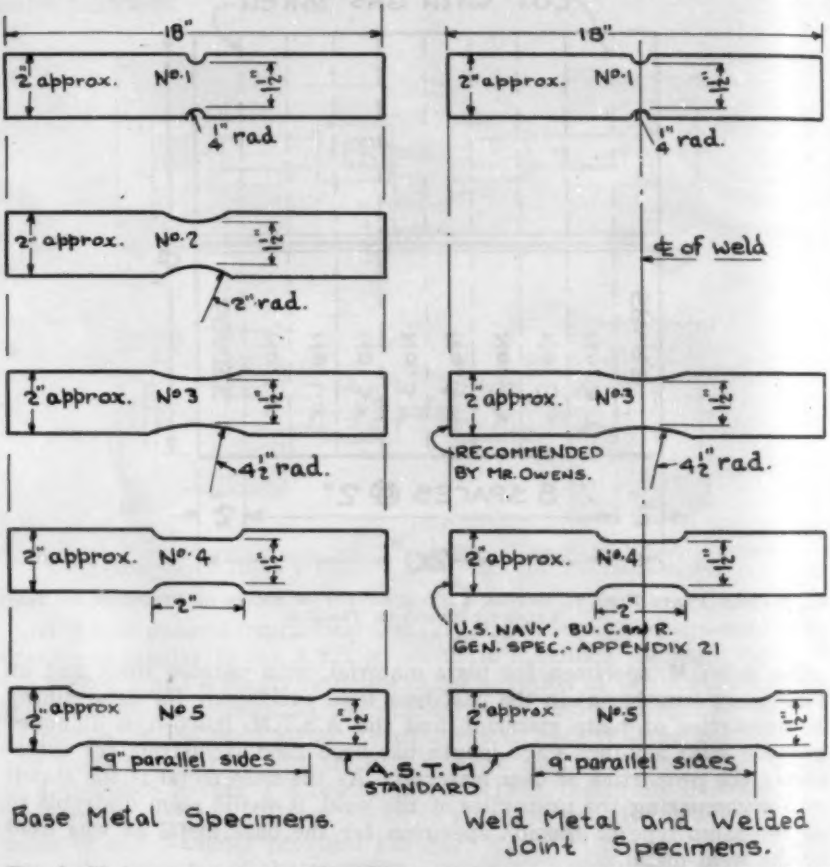


FIG. 3—METHOD OF PREPARING SPECIMENS AFTER REMOVAL FROM TEST PLATE, SHOWN IN FIG 2

if secured will give the ultimate tension stress value of the weld metal, as failure will usually occur through the throat of the weld. This specimen, however, will not give any reliable information on the percent elongation of the weld metal or its reduction in area. If the weld metal is "tough" this specimen, as will be shown later, may or may not show whether good fusion has been secured, and if, as is usually the case, failure occurs in the base metal, it only gives a general idea that the weld, as a welded joint, is stronger than the base metal. No information is

possible, however, on the percent elongation of the weld metal or its reduction in area, as practically all physical deformation of the specimen has taken place in the base metal at the point of failure.

When the weld metal is known to be "tough," some investigators have, for such specimens, either used base metal of a higher tensile strength than that of the weld metal, or locally reduced the section of the specimen at the weld. As previously pointed out, the use of base metal having a higher tensile strength than weld metal should never be employed, and as will be pointed out later, the results secured by a reduction of the weld section are, in many cases, either valueless, or do not give the information desired.

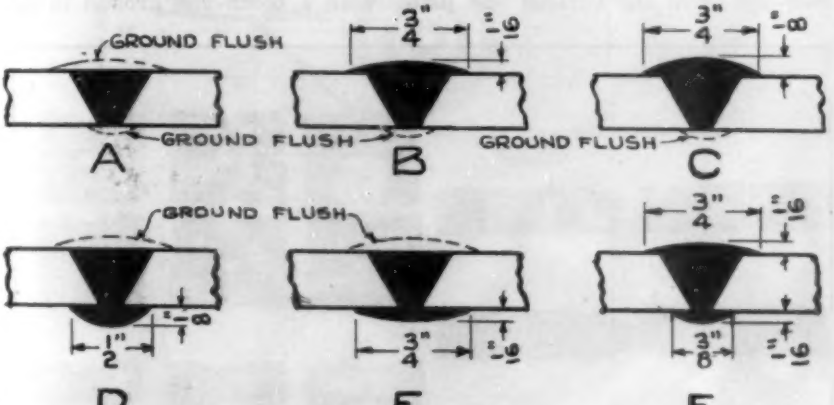


FIG. 4—FORMS OF WELD AND TYPES OF REINFORCEMENT FOR SPECIMENS SHOWN IN FIG. 3

Development of a Suitable Shape of Tension Specimen to Determine Fusion and the Value of the Weld as a Joint.

As a specimen transverse to the joint is necessary in the determination of fusion, and recognizing the influence of the variables mentioned on any values obtained, the writer outlined a series of tests for gas and arc welds to gather information on this subject, with the hope that a shape of tension specimen might be evolved which could be recommended to the Society as a standard for "brittle" and "tough" weld metal; for the testing of welders; for testing a process; and the testing of sample welds in a structure. The only tests completed are for "brittle" weld metal obtained by the metal arc process. The test plate used is shown in Fig. 2; the shapes of test specimens in Fig. 3; the forms of welds and types of reinforcement in Fig. 4; the specimens after test in Fig. 5; and the results of the tests in Fig. 6.

Six ⅜-inch test plates, Fig. 2, having the composition of standard ship plate with a carbon content of approximately 0.25 per cent, were welded with bare low carbon steel electrodes, complying with the American Welding Society Specification E1-B for electrodes. The weld metal obtained can be classed as "brittle" material.

A single V butt weld was used and the metal was deposited in two lay-

ers. The welds of each test plate were different, as shown in Fig. 4. On completion of the welds, eight specimens were cut from each test plate, thus providing for test two specimens (X and Y) of each shape of test specimen, and form of weld. While it is customary to test three specimens of each variable, nevertheless only two specimens were used in this case, in order to reduce the cost of the test. It is believed that the test results are consistent enough to permit reliable tentative conclusions.

In order to have a basis of comparison, two base metal specimens of each shape used were prepared as shown in Fig. 3. Two additional base metal specimens, No. 2, Fig. 3, were also prepared, having a shape midway between the shapes of specimens Nos. 1 and 3. The weld specimens were cut from the various test plates with a torch and ground to the

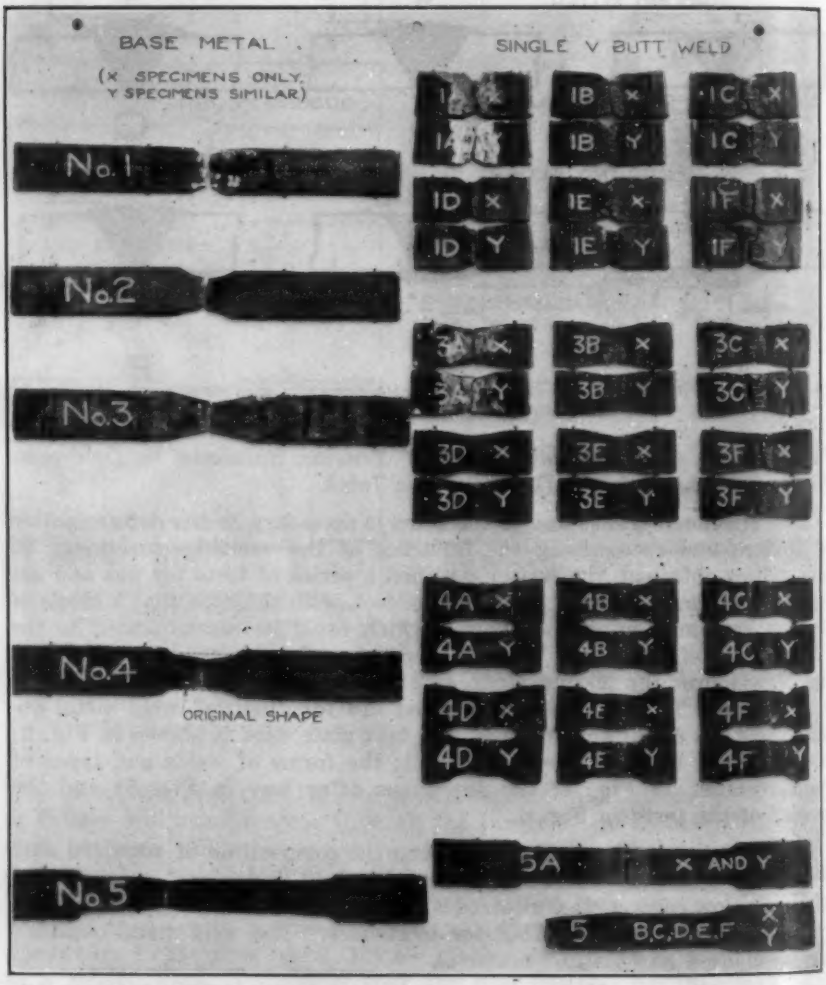


FIG. 5—SPECIMENS SHOWN IN FIG. 3 AFTER TEST

shapes required. The majority of the specimens, after test shown in Fig. 5, were reduced in size to facilitate mounting.

As the test specimens of welds would always be ground flush with the base metal, I have purposely eliminated including in the curves Fig. 6, the information secured on the other forms of weld and types of reinforcements, preferring to reserve this for a future paper.

A study of these curves will show the following:

(a) The ultimate stress values of the base metal specimens, regardless of shape, were consistently higher than the weld specimens.

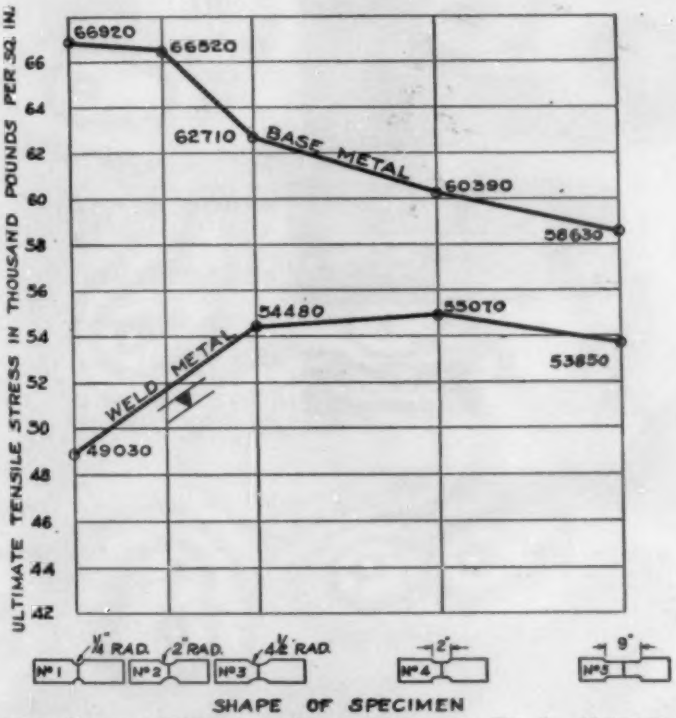


FIG. 6—CURVES SHOWING RESULTS OF TEST OF SPECIMENS—FIG. 2. (AVERAGE OF TWO SPECIMENS)

(b) The ultimate stress values of the base metal specimens increased as the length of the reduced area decreased, the increase being very pronounced when the sides of the specimen were notched.

(c) The ultimate stress values of the weld specimens with curved and parallel sides, Nos. 3, 4, and 5, did not show any appreciable difference, whereas the notched specimen No. 1 had a very low ultimate stress.

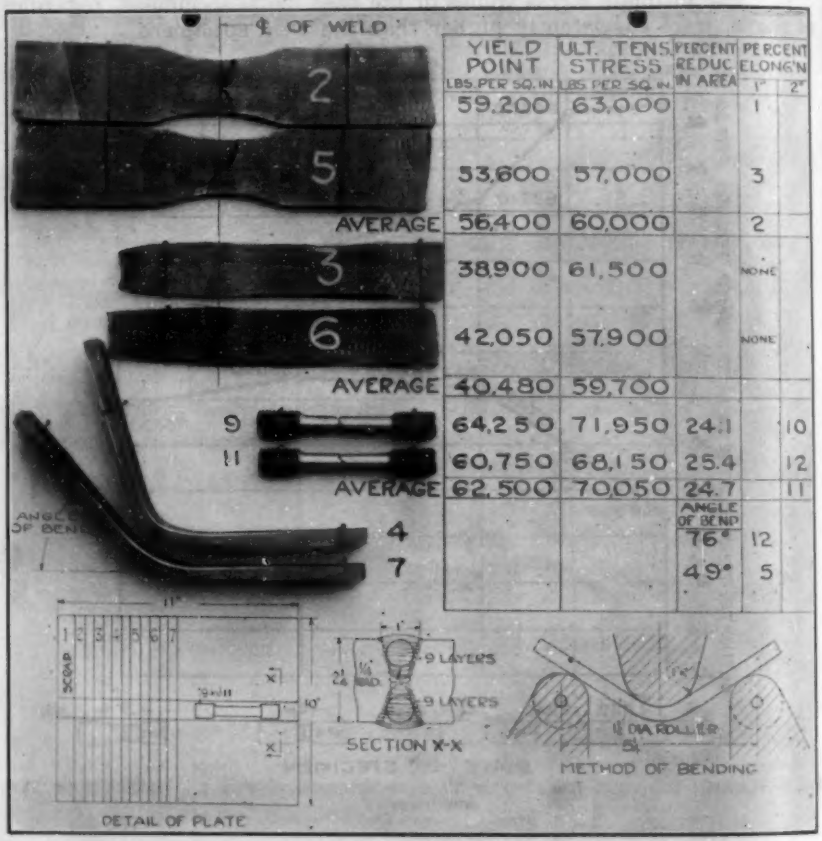
Note: All weld specimens fractured through the throat of the weld.

The practical conclusions to be drawn from this test are that:

(a) The notching of a specimen, whether of "brittle" or "ductile" material, will give inaccurate results. If the specimen is of brittle mate-

rial, the values of ultimate stress will be very low and if of a tough material these values will be very high. It might also be concluded from this test that when the weld section is reduced by the drilling of holes through the center of the weld, the ultimate stress values for the weld metal, thus obtained, will also be inaccurate.

(b) When the weld metal is brittle and failure consistently occurs in the weld, it does not make any difference whether specimens of shapes



YIELD POINT LBS. PER SQ. IN	ULT. TENS. STRESS LBS. PER SQ. IN	PERCENT REDUC. IN AREA	PERCENT ELONG'N 1"	PERCENT ELONG'N 2"
59,200	63,000		1	
53,600	57,000		3	
56,400	60,000		2	
38,900	61,500		NONE	
42,050	57,900		NONE	
40,480	59,700			
64,250	71,950	24.1		10
60,750	68,150	25.4		12
62,500	70,050	24.7		11
		ANGLE OF BEND 76°	12	
		49°	5	

FIG. 7—RESULTS OF TESTS OBTAINED WITH WELD METAL OF HIGH TENSILE STRENGTH AND FAIR DUCTILITY

Nos. 3, 4, or 5 be used. Practically, however, it would be an advantage to use specimen No. 3, as the curved reduction can easily be obtained on a grinding wheel and it avoids the possibility when grinding, of abruptly notching the section at the shoulders, this localizing possible failure at this point.

Considering the use of the curved specimen, No. 3, for welds with "tough" weld metal, Fig. 7 shows a test of a double V weld in 2¼ inch material made with a covered electrode, wherein the weld metal had an

ultimate stress of approximately 70,050 lbs. per sq. inch, as compared with 69,700 lbs. for the base metal. In this test we find that the tension specimens with parallel sides failed in the base metal at an average ultimate stress of 69,700 lbs., and the tension specimen with curved sides failed in the fusion zone at an average ultimate stress of 60,000 lbs. As the specimens with parallel sides were in the test plate adjacent to the specimens with the curved sides, and as there was poor fusion in the latter, it is probable that there was also poor fusion in the specimens with the parallel sides. If this assumption is correct, it would indicate that specimens with parallel sides will not necessarily show poor fusion in "tough" welds, whereas specimens having a curved shape will show poor fusion in such welds.

We have previously seen that when the weld metal is "brittle" the curved specimen will show not only poor fusion, but will give the ultimate stress value of the weld metal. It has also been shown that this shape of specimen will show defective fusion in "tough" welds, therefore it would appear that this specimen is equally applicable to both brittle and tough welds regardless of the object for which the test is made. The writer has therefore tentatively adopted this specimen, in conjunction with a bend test, for determining the fusion secured in metal arc butt welds.

It is hoped that other investigators will duplicate this series of tests with base metals having the same and different physical properties to the base metal used by the writer, but welded with processes wherein the weld metal has higher tensile strengths and excellent ductility.

Swivel Holders.

If the round specimen is adopted as a standard for determining the values in tension of the weld and base metals, it would be very desirable to encourage its use by reducing to a minimum the cost of preparing the specimen. In this connection, it is found that many testing laboratories thread the ends of the specimen. This can be avoided by the use of swivel holders similar to that shown in Fig. 1. As swivel holders have the advantage of insuring an equal distribution of stress in the specimen under test, it is recommended that their use be required.

Summary.

Summarizing the data and information contained herein, the writer submits the following recommendations for consideration of the Committee on Standard Tests for Welds:

(a) The values for ultimate stress, yield point, percent elongation, and reduction in area should be determined separately for the base and weld metals, by the use of round specimens similar to the A.S.T.M. standard specimen for cast materials. Where possible the diameter of this specimen should be 0.505 inch and the gage length 2 inches. However, where this is impractical, any diameter of specimen may be used provided the gage length is four times the diameter.

(b) The value for fusion for both "brittle" and "tough" welds should be determined by a rectangular specimen transverse to the joint, with parallel sides and edges, having the weld section locally reduced 25 per cent in width by a curved reduction at the edges of the specimen, the

radius of curvature being four times the width of the reduced weld section.

(c) The base metal used in the preparation of test specimen for welds should have the same properties as that used in the structure on class of work for which tests are made.

(d) The use of swivel holders should be required for testing the round weld and base metal specimens.

The Elimination of Joints in Open Track*

J. H. DEPPELER†

AT the Annual Meeting in April, 1929 I presented a paper on "Thermit Welding of Rail Joints for Main Line Track of Steam Railroads," which paper was published in the June 1929 JOURNAL. A brief résumé of that paper will make what follows more easily understood.

That paper was written after a careful investigation of the welding of steam railroad track in Germany and showed how this work had developed from a few experimental installations through a number where a thousand feet or more of track was made endless by Thermit Welding and where these thousand foot stretches, at first joined by expansion joints, were later joined by simple bolted joints without any expansion difficulties. The paper describes in detail the method of making the joint, compares the German and the American rail sections, and then shows the American joint which was developed to allow the welding of our heavier and very much harder rails.

Since that paper was written the work in Germany had continued unabated, the program of the German State Railroads being the conversion of 50 foot rail lengths into 100 foot. Apparently neither the thousand foot experimental stretches nor the sixty-thousand or more individual isolated joints have ever given them a bit of trouble.

In this country the work has proceeded with extreme caution because it is most important that two questions be answered. First, would the joint wear the same as the rail, and second, would not the elimination of the miniature expansion joints at the ends of each rail introduce difficulties from spreading gauge.

The answer to the first of these questions is found, we believe, in the installation we made in 1928 in the retarder track of the New York Central Railroad at their DeWitt Yards, East Syracuse. The type of joint used is shown in Fig. 1, and consists of a Thermit fusion weld of the bases and webs of the rails and a pressure weld of the head portions. In this DeWitt Yards installation there were almost one hundred joints and although they have been in for about two years, and it is estimated that twenty-five hundred (2500) freight cars pass over them each day, nevertheless these joints are just as perfect today as when they were installed. Fig. 2 shows a general view of the installation, and Fig. 3, a

*Paper to be presented at Fall Meeting, A. W. S., Chicago, September, 1930.
†Chief Engineer, Metal & Thermit Corporation.

close-up of one joint. This installation, therefore, we believe answers the first question and it is our firm conviction that with this type of rail joint, although a little more expensive than that used in Street Railway practice and a little more cumbersome to install, there is absolutely no doubt that the joint will wear no more or no less than the rail and will always present a smooth, even riding surface.

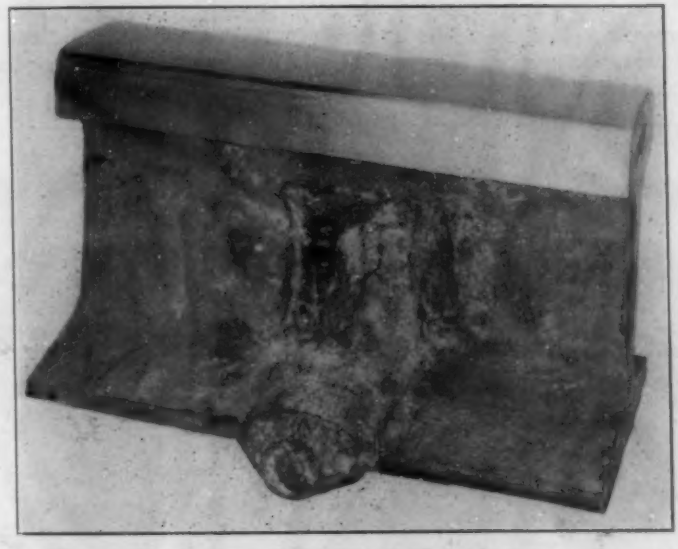


FIG. 1—THERMIT PRESSURE RAIL WELD

But the second question is naturally the most difficult to answer and regardless of the troubles that he is experiencing in his bolted joints the Engineer Of Way is bound to be slow to adopt a method which on first thought would seem to introduce enormous strains and might result in broken rails in winter and spreading gauge in summer. An elaborate mathematical calculation has been worked out to prove that where the joints were welded with due regard to the temperature at the time of welding, the maximum temperature variation between summer and winter would cause no trouble, but such a calculation must be supported by experiment and so far few American engineers have been willing to make these more elaborate experiments.

The German engineer feared the consequences less because his rails were lighter and very much softer and more ductile; their maximum carbon content was only about 0.40 as compared with our 0.80 and 0.90. The experience in Germany has definitely indicated that the resistance of the weight of the rail, the friction on the tie plates, etc., cause temperature changes to have no greater effect than to change the compression strains in the rail and that even in a thousand feet of rail without joints, ordinary bolted joints may be used at the end and that the opening and closing of these bolted joints are only about the same as for a single rail length.

The American engineer's experience has led him to believe that this cannot be true because even his relatively short rail lengths have given him trouble, the joints closing up completely in extremely hot weather and the track buckling. We believe, however, that this apparent discrepancy between the supposed facts here and abroad can be easily explained. The standard construction abroad includes a tie plate with a shoulder on each side of the base of the rail, whereas in the usual construction in this country the tie plates have only a single shoulder. It is our present belief that this apparently slight difference is really of major importance and we believe that the few experimental installations already made in this country support this idea.

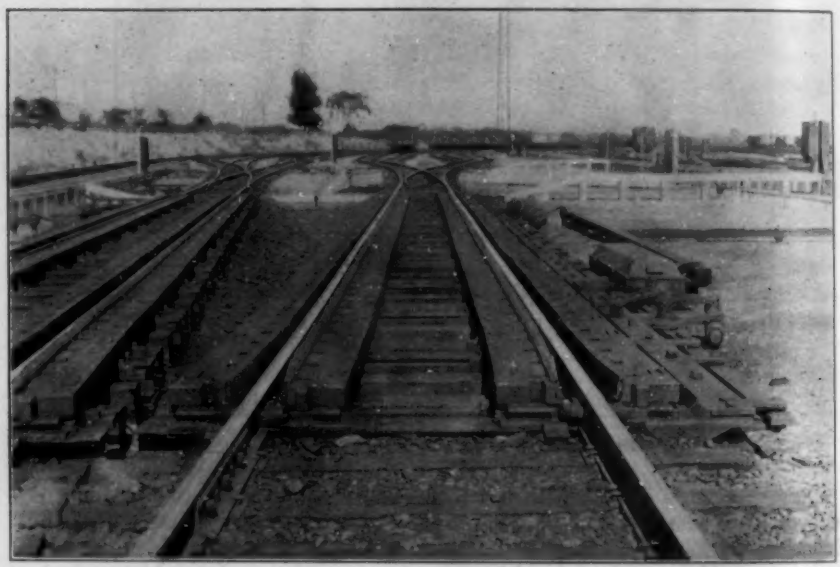


FIG. 2—WELDED RETARDER TRACK IN DE WITT YARDS, EAST SYRACUSE

A double shoulder tie plate does not, of course, fit the rail base closely, but the slightest tendency for the rail to warp brings the rail base into contact with the diagonally opposite shoulders of the tie plate and this friction added to the weight of the rail and the friction of the spikes does apparently prevent the rail from moving during temperature changes.

We mentioned above experimental installations in this country which seem to bear out these apparent facts. One of these is not a welded track at all, but is the installation of about five miles of the main line track of the Lehigh Valley Railroad near Towanda, Pa., in which 66-foot rails of 136 pound L.V. Section were used instead of the standard length of 33-foot rails. This installation was described in "Railway Engineering and Maintenance," May 1930, Volume 26, No. 5, as having been made March 23, 1929, and in this description the prior German practice is referred to in the following quoted paragraph:

"It has been common practice on the German State Railways for some time to use rails 30 meters, or 98.42 ft. in length, and in many cases these long

rails are welded together. A conference with Dr. Buckholtz of the German State Railways indicated that no trouble was being experienced, insofar as expansion was concerned, even though very limited openings were allowed at the joints."

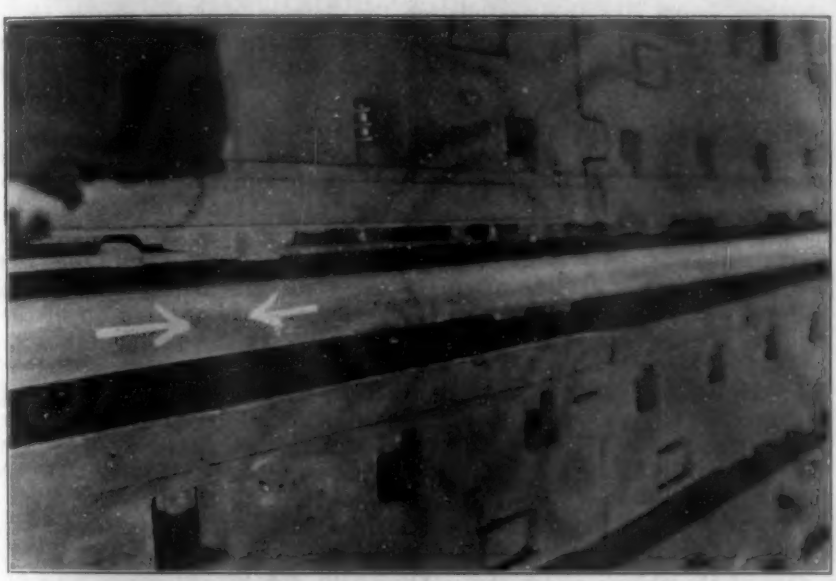


FIG. 3—CLOSE-UP OF JOINT IN WELDING RETARDER TRACK, DE WITT YARDS, EAST SYRACUSE

The article refers also to studies that had been made in America wherein long stretches of 33-foot rails were found tight together and so firmly fastened that expansion was impossible. In this Lehigh Valley installation made with 66-foot rails, six-hole, 38-inch angle bars and the rails laid on double shoulder tie plates, the temperature at the time of laying was between 35 deg. and 40 deg. Fahrenheit and the rails were laid practically tight. At the time the article was written the rails had passed through the extremely hot weather of the summer of 1929 and the subsequent winter and during this hot weather the entire five miles was raised and surfaced without any tendency for the track to swing out of line or become "kinky." Since this installation was made the article says that the temperature has ranged from 35 deg. to 100 deg. Fahrenheit and that at no time has there been evidence of expansion or contraction, in fact "the rail has, for all practical purposes, remained exactly as originally placed."

Looking at this Lehigh Valley installation it does not seem reasonable to suppose that the reason no trouble was experienced is because of the existence of a tight joint every 66 feet instead of a welded joint.

Another installation which offers proof that welded open track will give no trouble from expansion is one in Chicago on Vincennes Road. Although this is Street Railway track, nevertheless it is exposed "T" rail and the construction practically the same as for railroad track. In this

particular installation the double shoulder tie plate is not used, but in its stead one side of the base of the rail was held by the single shoulder of the tie plate and the opposite side by a rail clip which, fulcrumed about the spike, would tend to gag the rail in the same way that the double shoulder would. In this installation the four rails of the double track were welded in stretches of fourteen, twenty and sixteen rail lengths with ordinary bolted joints between. Here again no difficulty has been experienced from expansion.

It is probably superfluous to point out the importance of the elimination of rail joints, but the layman's impression is that except for the slight noise they introduce no difficulty. On the other hand the facts are that with the increasing weight of equipment and the greater speed and number of train movements, steam railroad track is really very difficult to maintain and it is reported that various railroads are considering the use of alloy steel rails, the use of heat-treated rails, and rails weighing 200 pounds per yard in an attempt to eliminate the spalling off of the rail end and the serious danger of broken rails. In our opinion the welding of the rail ends is the only solution because regardless of whether the rails are alloy steel, or heat-treated, or weigh 200 pounds per yard or more, the effect of the blow of the heavy wheel loads passing over the joints cannot, we believe, be eliminated in any other way. It is our belief also that the elimination of this constant shock and vibration of the rails, due to the blows at the joints, may greatly delay, if not eliminate, the crystallization and fatigue of the rail steel and may possibly eliminate the rail fissures which cause the engineer so much worry today.

One of the things which the welding will definitely do away with is creepage and it seems very possible that this may be the cause of many of the broken rails and the numerous instances of spreading gauge. Creepage is undoubtedly a function of the rail length so that in a certain location each length will tend to move, usually in the direction of traffic, a certain distance for each passing wheel load. If this be true ten 33-foot lengths will tend to creep ten times as far as one 330-foot stretch of welded track and the experience so far with these long welded stretches bears this out. Creepage is only partially eliminated by the numerous designs of anti-creepers and it does not take much imagination to picture the enormous tension strains introduced into tangent track and the effect of this accumulation of creepage in the spreading of the gauge at curves. It is probably true that these enormous tensions are much greater than any tension that could possibly be introduced by a severe drop of temperature on welded track and it is our opinion at least that the strains, due to temperature, are always very small compared with the elastic limit of the rail and the elimination of shock makes these strains of even less importance.

A few years ago a railroad engineer would not allow heat of any kind to touch his rail, but most of them are now using one welding process or another to build up worn or pounded rail ends and have found no serious consequences. It is but a little step further to weld these rail ends and as soon as he is convinced that prohibitive strains will not be introduced by the endless track so made it is certain that the enormous advantages will repay many times over the slight additional cost of welding.

The Application of Fusion Welding to Pressure Vessels*

J. C. HODGE†

THE present discussion of welded pressure vessels is confined to welded vessels made by that division of welding described as the fusion welding process, and, particularly, by that subdivision of fusion welding known as metal arc welding. Pressure parts have been made by the other two welding processes—forge welding and electric resistance butt welding, but each of these processes has its limitations as to the size of the pressure parts which can be welded.

Large numbers of metal arc welded pressure vessels have been made for several years. For the most part, these welded pressure vessels have been confined to air and gas containers and other equipment operating under low pressures and temperatures. The application of welded construction to pressure vessels for high temperature and high pressure service is a comparatively recent development and this paper is centered on a consideration of this type of welded pressure vessel.

The general acceptance of welded construction in pressure vessels which were to operate under severe conditions has been very greatly retarded for several reasons:

1. The average bare electrode weld as used in constructions which operate under conditions not relatively severe could not be used because the weld metal, even when free from major defects, is characteristically brittle.

2. There has been a lack of agreement regarding the desirable physical, chemical and other properties of welded joints. This was particularly true regarding the behavior of welded joints under repeated applications of stress and was also true regarding the behavior of welded joints under high temperature conditions.

3. The greatest objection to the use of welded pressure vessels was undoubtedly the absence of a definite testing procedure which would assure the reliability of the completely welded drum.

There are numerous factors affecting the suitability of welded pressure vessels for severe service conditions. These numerous variables may be grouped into the following major divisions:

1. The design of the vessels.
2. The metallurgical and chemical qualities of the welded joints which in turn depend upon the electrodes and on the welding technique employed.
3. The heat treatment of the finished welded vessel.
4. The testing procedure.

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*Paper to be presented at Fall Meeting, A.W.S., Chicago, September, 1930.

†Babcock & Wilcox Company, Barberton, Ohio.

The two most important factors which are of greatest interest at the present time are the quality of the welded joints and the testing procedure to determine the properties and quality of the welded joints. The present paper will, therefore, be restricted to a discussion of these two phases of welded vessels.

Ordinary arc weld metal (weld metal deposited from bare electrodes),

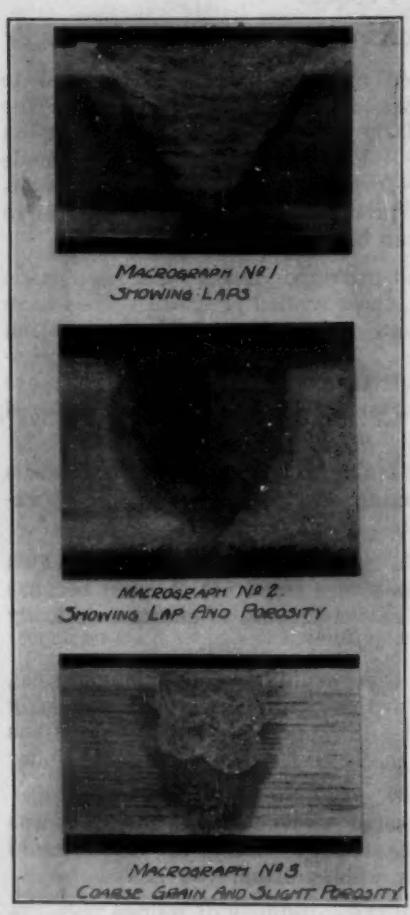


PLATE I

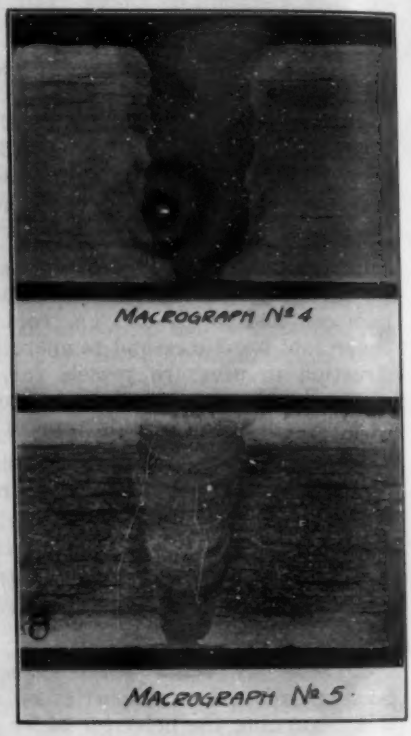


PLATE III—MACROGRAPHS FROM PRESSURE VESSEL WELDS. NOTE FREEDOM FROM MAJOR DEFECTS

even when deposited by a thoroughly competent operator, will usually contain a large number of major defects, such as porosity, oxide inclusions, laps, incomplete fusion, etc. Typical major defects are shown in macrographs Nos. 1 and 2 (Plate No. 1). Even when free from major defects as in macrograph No. 3, plate No. 1, the ordinary arc weld metal is quite brittle, due to the fact that the bare electrodes have no protection from the gases of the atmosphere and consequently nitrides and oxides are present in the deposited weld metal.

Photomicrographs Nos. 1 to 6 (Plate 2) are typical of the structures observed in average bare electrode weld metal. Photomicrograph No. 1 represents the coarse cast columnar structure of single bead deposition,

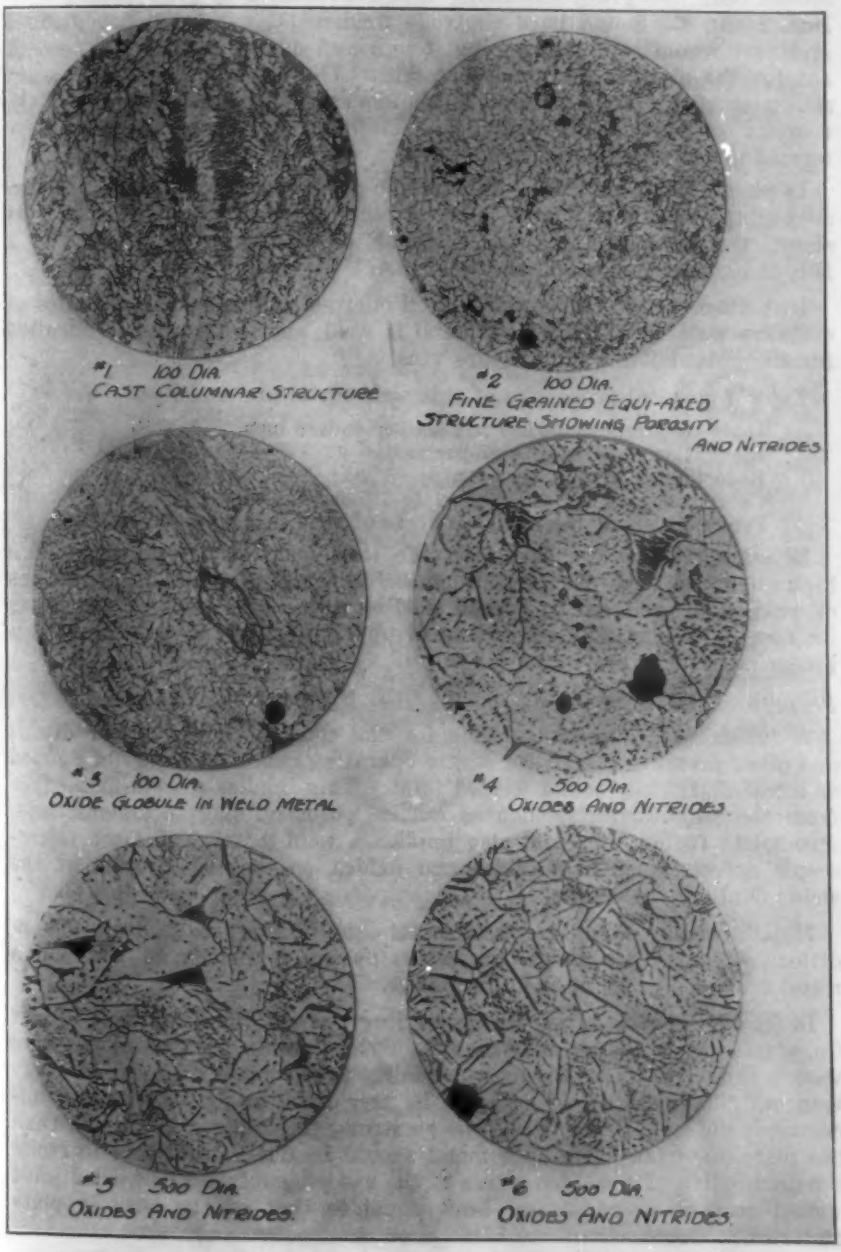


PLATE II—TYPICAL PHOTOMICROGRAPHS OF BARE ELECTRODE WELD METAL

brittleness of the weld metal being associated with this type of structure. When a second bead is deposited over this bead of coarse columnar structure, the structure is more or less refined by the annealing heat of the second bead, the grain size being then represented by photomicrographs Nos. 2 and 3. Sound bare electrode weld metal with this fine grained structure would represent strong, tough and ductile weld metal were it not for the nitrides and oxides present. These nitrides and oxides are shown at higher magnification in photomicrographs Nos. 4, 5 and 6, the rounded oxide inclusions and the needle-like constituents which we have termed nitrides being readily observed.

In photomicrograph No. 2 microscopic porosity is shown, and in photomicrograph No. 3 a defect quite common to ordinary weld metal is shown, the defect consisting of a globule of weld metal surrounded by a film of oxide embedded in the weld metal.

Due, then, to the above macro- and micro-structural characteristics of ordinary weld metal, this weld metal is weak and brittle and is unsuited for the welded joints of pressure vessels.

Typical physical properties of this weld metal are as follows:

Ultimate strength, 50,000 pounds per square inch.
Elongation in 2 in., 5 to 18 per cent.
Reduction of area, 15 per cent.
Charpy notched impact value, 1 to 8 foot pounds.
Per cent elongation on outside fibers of bend test, 5 to 10 per cent.

Between the average bare electrode weld metal and weld metal of a high quality suitable for pressure vessel service, there are all gradations of weld metal produced by special welding procedures, each of which has its own particular field of successful application in the welding of engineering structures.

Properties of Welded Joints for Pressure Vessels

A fusion welded joint, suitable for the construction of boiler drums and other pressure vessels for severe operating conditions, may be defined as a metallurgically sound welded joint. This implies a weld metal free from the major defects, such as cracks, porosity, slag inclusions, laps, incomplete fusion, etc., and also implies a weld metal free from microscopic defects, such as nitrides and oxides, so that the ferrite of the weld metal will be ductile.

Metallurgically sound arc weld metal can only be produced under conditions which give complete protection during deposition of the molten metal from the gases of the atmosphere.

In its development of its fusion welding process, the Babcock & Wilcox Co. started with the premise that the welded joints for welded pressure vessels should be at least equal in quality to the plate material in every respect. The welded joints should be free from major defects and microscopic defects. They should be as strong or stronger in tension than the plate material. The weld metal should be ductile and able to resist the application of a sudden stress to the welded joints. The welded joint should possess an endurance limit equal to that of the base or plate material.

Typical physical, chemical and other properties of the fusion welded joints developed by this process are presented as satisfying all of the above conditions.

Macroscopic and Microscopic Examination

Typical sections across the welded joints are shown in macrographs Nos. 1 and 2 (Plate 3). The freedom from macroscopic defects is striking when compared with the porosity, lack of fusion, laps, etc., which have been presented as characteristic of ordinary bare electrode weld metal. The perfection of the line of fusion between weld metal and base metal should be particularly noted.

By careful control of the annealing procedure offered by multiple bead deposition (that is, by utilizing the heat of weld metal during deposition to refine the structure of the previous bead), the coarse cast columnar structure of single bead deposition is eliminated and photomicrograph No. 1 (Plate 4) may be taken as typical of the grain size of the weld metal. By this procedure, an annealing of the completely welded drum at a high temperature for refinement of the grain is unnecessary. A stress relieving treatment for the removal of residual welding stresses is all that is required and this may be accomplished at a relatively low temperature, approximately 1200 deg. F., so that distortion and sagging of the drum during annealing is at a minimum.

Photomicrographs No. 2 and No. 3 (Plate 4) show the structure of the weld metal at a higher magnification, no nitride needles or oxide inclusions being present.

Photomicrograph No. 4 represents the structure of the original plate material and photomicrograph No. 5 (Plate 4) represents the junction of the weld metal and base metal. The structure of the affected zone of the plate immediately adjacent to the weld metal is superior to that of the original plate.

Weld metal with the above macro and micro-structural characteristics should possess excellent physical properties and the welded joint should be suitable for pressure vessels.

Tensile Properties

On tension specimens cut transverse to the welded joint failure always occurs in the plate, provided the plate complies with the A.S.M.E. boiler code specifications for firebox plate, although the section through the weld is the same as that through the plate.

By reducing the effective cross section of the weld metal by drilling holes in the weld metal, failure is made to occur in the weld metal and the actual tensile properties of the weld metal are thus obtained.

Tension specimens transverse to the welded joints do not give values for the elongation and reduction of area of the weld metal, which can be readily compared with values for other steels. These properties can be obtained on all weld metal tension specimens, standard .505 in. dia. by 2 in. gage length cut from the weld so that the axis of the specimen is parallel to the axis of the joint. The tensile properties are summarized in Table I.

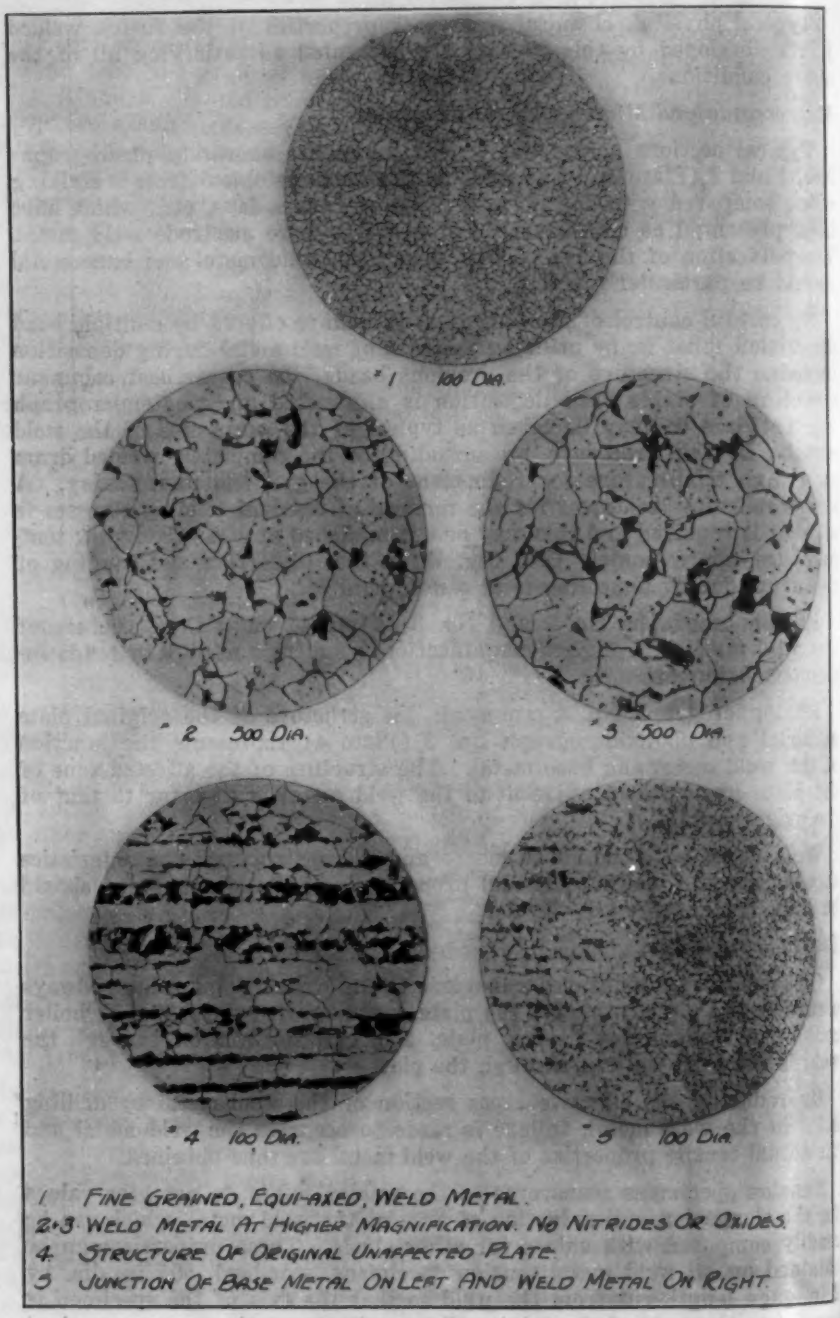

#1 100 DIA.
#2 500 DIA.
#3 500 DIA.
#4 100 DIA.
#5 100 DIA.
1 FINE GRAINED, EQUI-AXED, WELD METAL.
2-3 WELD METAL AT HIGHER MAGNIFICATION. NO NITRIDES OR OXIDES.
4 STRUCTURE OF ORIGINAL UNAFFECTED PLATE.
5 JUNCTION OF BASE METAL ON LEFT AND WELD METAL ON RIGHT.

PLATE IV—PHOTOMICROGRAPHS TYPICAL OF THE PRESSURE VESSEL WELDED JOINTS OF THE B. & W. CO.

TABLE I

	A.S.M.E. Firebox Plate	Pressure Vessel Weld Metal	Bare Electrode Weld Metal
Transverse Specimens			
Ultimate Strength, lbs./sq. in.			
Min.	55,000	65,000	
Max.	65,000	74,500	56,000
Ave.		67,500	50,000
Yield Point, lbs./sq. in.			
Min.	1/2	47,000	
Max.	Ult.	58,900	50,000
Ave.	Str.	51,000	42,000
All Weld Metal Specimens			
Yield Point, lbs./sq. in.			
Min.	Not	40,000	35,000
Max.	Spec.	65,000	50,000
Ave.		52,000	42,000
Ultimate Strength, lbs./sq. in.			
Min.	Not	60,000	40,000
Max.	Spec.	72,000	63,000
Ave.		67,000	52,000
Elongation in 2 In.			
Min.	Not	20.5	5.0
Max.	Spec.	38.0	18.0
Ave.		28.0	8.0
Reduction of Area			
Min.	Not	32.0	10.0
Max.	Spec.	65.0	25.0
Ave.		40.0	15.0

A set of six tension specimens with an increasing number of holes drilled in the weld metal is shown in Plate 5 and the data obtained on these six specimens are given in Table II.

It is to be noted that fracture occurred in the weld metal in one specimen only, where the effective cross section of the weld metal had been reduced to 65 per cent of the section through the plate and where the breaking load of the weld metal was as high as 74,200 pounds per square inch.*

The stress strain diagram of this weld is of interest. A typical diagram of the weld metal and a typical stress strain diagram of well annealed plate are shown in Fig. 1 A and B. Both types show a decided yield point. The slope of the curve in the region of the yield point is practically zero, indicating that considerable deformation of the metal takes place in this region without a great increase in load. An enlarged view of the stress strain diagram for the weld metal through the yield point is also shown in Fig. 1, this portion of the diagram indicating that in good weld metal deformation at the yield point is in effect a successive series of slips, similar to the yielding in a well annealed low carbon structural steel.

Bend Tests

The bend test is of considerable value in determining the ductility of the weld metal in a welded joint. Following the method of determina-

*This tensile strength is probably somewhat higher than it would be with a test specimen of ordinary proportions.

tion of the satisfactory behavior of a welded joint under bending proposed by Mr. Kinzel of the Union Carbide Laboratories, the ductility is expressed as the per cent elongation in the outside fibers of the weld metal during bending. Values for this weld metal have been found as

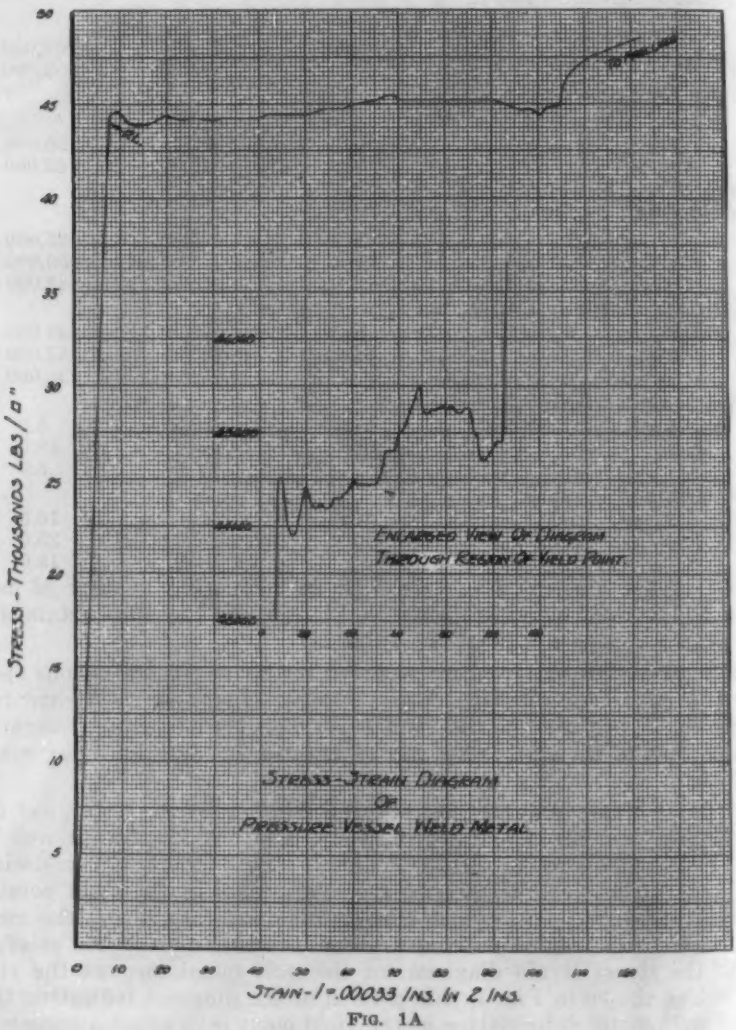

STRESS - THOUSANDS LBS / □"
ENLARGED VIEW OF DIAGRAM THROUGH REGION OF YIELD POINT
STRESS-STRAIN DIAGRAM OF PRESSURE VESSEL WELD METAL
STAIN-1=.00033 INS. IN 2 INS.

FIG. 1A

high as 65 per cent, while the average per cent elongation of the outside fibers is approximately 50 per cent.

A bend test specimen may be bent around a mandrel of a diameter equal to the thickness of the plate to an angle 180 deg. An idea of the extreme ductility of the weld metal shown by the bend test may be obtained from an examination of plate No. 6.

TABLE II

B. & W. Metal Arc Welded Joint

Tensile Tests						
Spec. No.	1709	1710	1711	1712	1713	1714*
1/8" Dia. Holes in Weld	Solid	1-Hole	2-Holes	3-Holes	4-Holes	5-Holes
Original Dimensions:						
Thickness, ins.	1.820	1.820	1.820	1.813	1.825	1.820
Width, ins.	0.465	0.516	0.510	0.483	0.516	0.497
Area of Plates Section, sq. in.	0.846	0.938	0.928	0.876	0.941	0.904
Area of Weld Section, sq. in.	0.846	0.874	0.800	0.695	0.683	0.593
Ratio, Weld Area: Plate Area	1.0	0.93	0.86	0.79	0.72	0.65
Load on Plate at Yield Point, lbs.	20,000	21,900	21,300	20,000	22,000	21,000
Load on Weld at Yield Point, lbs.	30,000	34,400	33,100	27,750	34,400	30,500
Max. Load on Specimen, lbs.	43,000	46,600	45,600	43,700	47,500	44,000
Yield Point of Plate, lbs./sq. in.	23,650	23,320	22,950	22,820	23,400	23,600
Yield Point of Weld, lbs./sq. in.	35,470	39,400	41,400	39,900	50,300	41,400
Max. Stress on Plate, lbs./sq. in.	50,800	49,700	49,200	49,900	50,500	48,700
Max. Stress on Weld, lbs./sq. in.	50,800	53,300	57,100	62,900	69,400	74,200
Fracture	In plate	In plate	In plate	In plate	In plate	In weld through holes

*Spec. No. 1714 is the only specimen which failed through the weld metal due to the large reduction in cross section.

Impact Resistance

The impact test is better described by the term "Notched bar impact test," inasmuch as this term suggests a more accurate interpretation of what is accomplished by the testing, namely, the ability of the test specimen to resist the growth of a crack, once started in the metal. The greatest value of the notched bar impact test is that it gives the most useful indication as to whether or not a steel has been heat treated properly.

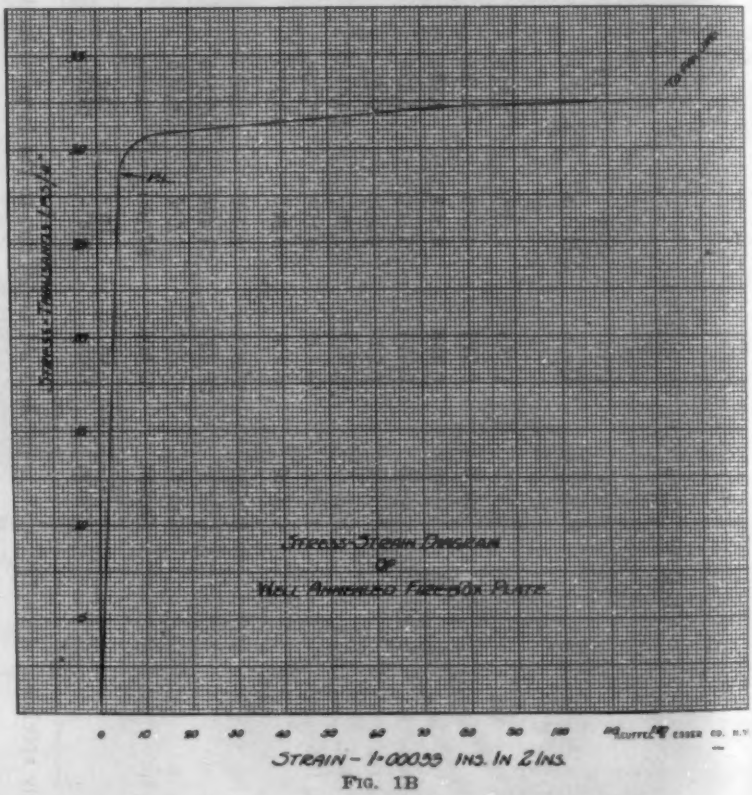


FIG. 1B

As applied to weld metal, the presence of a large amount of the coarse cast columnar structure already described will be indicated by low impact values. So also will a weld metal, inherently brittle by reason of its oxide and nitride contact, behave.

Standard 10 mm by 10 mm Charpy impact specimens give the following values for weld metal suitable for pressure vessels as compared with other steels.

TABLE III

	Min.	Max.	Ave.
A.S.M.E. boiler plate—as rolled.....	19	33	20 ft. lbs.
Weld metal—made with bare electrodes.....	1	8	5 ft. lbs.
Pressure vessel weld metal	20	45	28 ft. lbs.

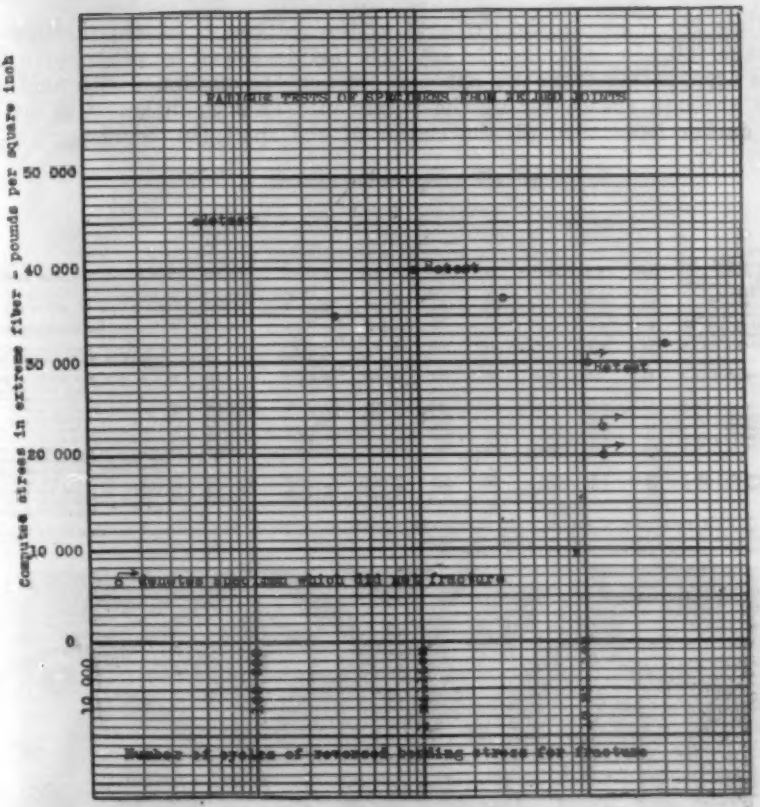


FIG. 2

Laboratory Fatigue Tests

Prof. H. F. Moore has conducted laboratory tests to determine the endurance limit of this special arc weld metal. His tests have shown the remarkably high endurance limit of 30,000 lbs./sq. in. for the weld metal as compared with an endurance limit of 28,000 lbs./sq. in. for Firebox quality plate. A copy of the results of his laboratory test follow (Table IV and Fig. 2):

TABLE IV

All material was furnished in the form of bars turned to 0.4 in. dia. All fatigue tests were made on rotating beam testing machines using a specimen 12 inches long and 0.300 inches in diameter (minimum).

Specimen	Computed Stress, Lb. per Sq. In.	Cycles for Fracture	Remarks
4[a]	45,000	46,600	Retest of Specimen 4
2[b]	40,000	970,700	Retest of Specimen 2
1	37,000	3,278,500	
5	35,000	311,800	
3	32,000	34,855,300	
2[a]	30,000	10,384,200	Specimen did not fracture
4	23,100	13,697,400	Specimen did not fracture
2	20,000	13,814,800	Specimen did not fracture

Plate No. 7 shows the surfaces of the fatigue fractures through the weld metal. In each case the fracture had developed by progressive failures propagating from two opposite sides of the specimen with final rupture through the center of the specimen. This condition is shown by the darker band through the center of the specimen, corresponding to

TABLE $\overline{V}$ SUMMARY OF TEST RESULTS

Specimen	Shell dimensions Inside diam., in.	Plate thickness, in.	Longitudinal seams	Efficiency of joint, per cent	Max. allowable working pressure, lb. per sq. in.[a]	Range of test pressure, lb. per sq. in.	Range of tensile hoop stress	No. of cycles of pressure applied during test	Remarks
Manganese-steel test drum, riveted	33¼	1.0	2 at 180°	71	698	0–1380	0–31,800	130,225	Crack in drum head below manhole
A.S.M.E. standard riveted drum	42	2.0	One	80	525	0–1380	0–16,800	1,013,840	No fracture
Forged test shell	42	1⅞	None	100	1047	0–1570	0–18,000	440,950	Failed at ⅛-in. tap hole for gage
Forge-and-hammer-welded shell No. 12	42	2.0	One	...	665	0–1570	0–18,000	880,000	No fracture; test still in progress
Forge-and-hammer-welded shell No. 13	42	2.0	One	...	665	0–1570	0–16,800 0–14,6800	611,164	Failed in plate away from weld at a longitudinal defect on the inside surface
Arc-welded shell No. 1	42	2.0	One	90	665	0–1570	0–16,800	5,530	In long. seam near middle of length at junction of base metal and weld metal. Bare welding wire used
Arc-welded shell No. 2	42	2.0	One	90	525	0–1570	0–16,500	267,803	Through slag inclusions in weld
Arc-welded shell No. 3	42	2.0	One	90	525	0–1570	0–16,500	417,381	Failed at ⅛-in. tap hole for gage
Arc-welded shell No. 4	42	2.0	One	90	525	0–1570	0–16,500	561,964	Same as for shell No. 2
Arc-welded shell No. 5	42	2.0	One	90	525	0–1570	0–16,500	435,563	Same as for shell No. 2
Arc-welded shell No. 6	42	2.0	One	90	525	0–1570	0–16,500	56,942	Tapped hole for gage located in weld hole very irregular at inner surface failure occurred at the tapped hole
Arc-welded shell No. 7	42	2.0	One	90	525	0–1570	0–16,500	1,025,027	No failure; no tapped hole in shell
Arc-welded shell No. 8	42	2.0	One	90	525	0–1570 0–2100	0–16,500 0–22,000	1,264,420 34,400	No failure; no tapped hole in shell No failure—supplementary test of shell No. 8; test still in progress

[a] Given by A.S.M.E. Power Boiler Code except for arc-welded shells where the maximum allowable working pressure is that given by the "Proposed Specifications for Fusion Welding of Drums or Shells for Power Boilers."
[b] Stress across welded seam, which is ⅛ in. thicker than plate.

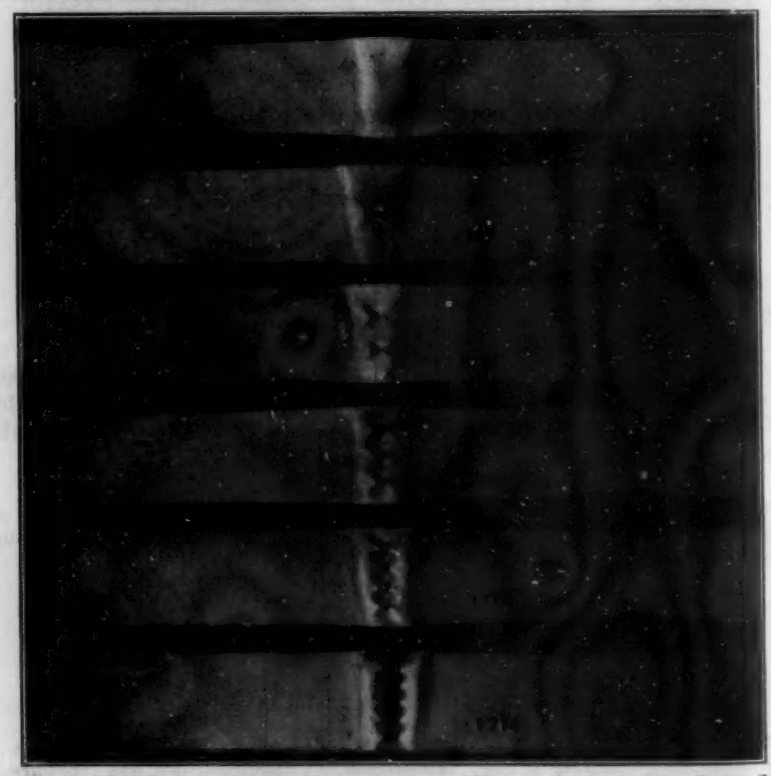


PLATE V—TENSION SPECIMENS TRANSVERSE TO WELDED JOINT. (FOR DATA SEE TABLE II)

the fracture by overstressing, with the lighter zones at the top and bottom, corresponding to the two progressive fractures; this condition illustrates perfectly the great homogeneity of the weld metal, for if small defects had been present these "stress raisers" would undoubtedly have localized the progressive failures and only one progressive failure would normally have been present.

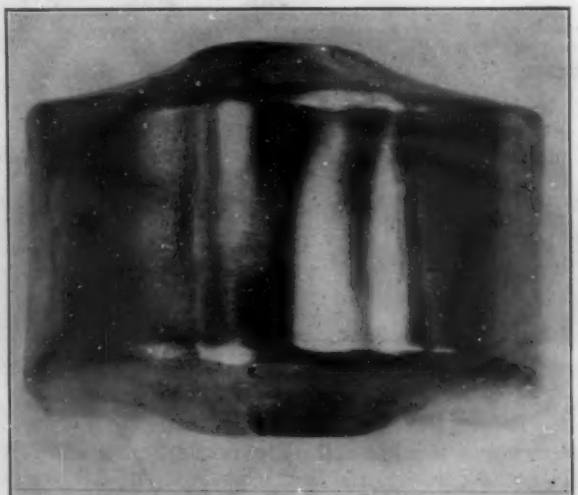


PLATE VI—BEND TEST SPECIMEN FROM 2 IN. THICK WELDED PLATE

Density

The density or specific gravity of various weld metals offers a very convenient method of determining the relative amounts of voids or porosity present in weld metals.

	Specific Gravity			Average Density,
	Min.	Max.	Ave.	Lbs./Cu. Ft.
Bare electrode weld metal.....	7.44	7.68	7.59	473
Pressure vessel weld metal.....	7.80	7.85	7.83	488
A.S.M.E. firebox plate.....	...	...	7.84	489

Assuming the theoretical value of the specific gravity of solid rolled low carbon plate as 7.85, the above values correspond to the presence of 3.3 and 0.12 per cent voids respectively, in ordinary weld metal and the

PLATE VII—SHOWING SURFACES OF FRACTURE THROUGH THE WELD METAL IN FATIGUE TEST SPECIMEN. THE CHARACTER OF THE FRACTURE INDICATES RELATIVELY GREAT HOMOGENEITY OF THE WELD METAL

special pressure vessel weld metal. The minimum value of 7.44 for bare electrode weld metal corresponds to the presence of 5.2 per cent voids.

Chemical Anaylsis

The chemical composition of pressure vessel weld metal as compared with boiler plate and with bare electrode weld metal is given in Table V.

TABLE V

	Firebox Plate	Pressure Vessel Weld Metal	Bare Electrode Weld Metal
Sulphur	Less than 0.04	Less than 0.045	Less than 0.045
Phosphorus	Less than 0.04	Less than 0.040	Less than 0.040
Manganese	0.30 to 0.60	0.30 to 0.60	Less than 0.20
Carbon	Not over 0.30%	0.08 to 0.15	0.02 to 0.08
Nitrogen as iron nitride..	Not spec. Will not usually be over 0.009	Less than 0.02	0.10 to 0.14

A comparison of the above values (particularly the nitrogen contents and the manganese contents) indicates that the weld metal suitable for pressure vessel welding was deposited under conditions which gave the greatest protection to the molten weld metal from the gases of the atmosphere.

Drum Tests

After the development of the welding process which produced welded joints with the excellent properties, heretofore described, a series of full sized arc welded test drums and shells were built and tested to destruction, both by straight hydrostatic pressure and by repeated applications of pressure (fatigue failure). The test to destruction by static hydraulic pressure has been repeatedly described in the technical literature. No

data for this type of testing of welded pressure vessels will be given in this present report other than the statement that the experimental welded pressure vessels with welded joints of the type described above always failed in the boiler plate, when the test pressure had reached a value corresponding to a fiber stress in the drum or shell within the tensile range of the plate used (55,000 to 65,000 pounds per square inch).

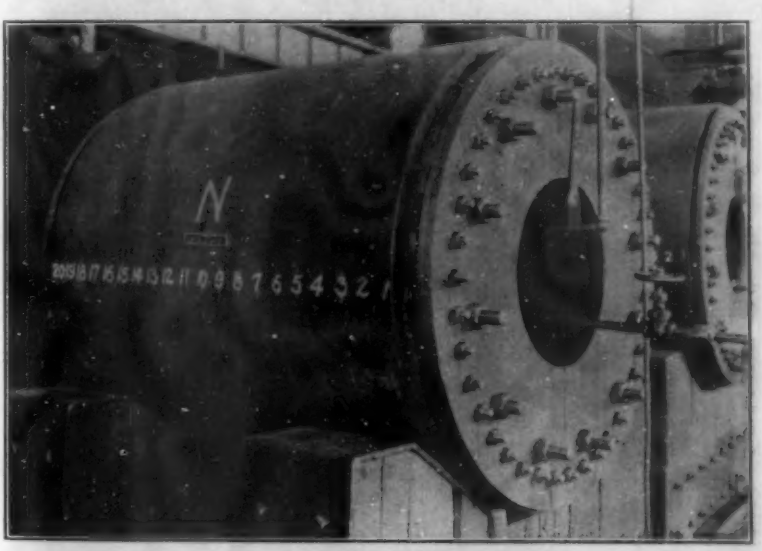


PLATE VIII—FATIGUE TEST ASSEMBLY FOR FULL SIZED FUSION WELDED SHELLS

The testing of pressure vessels to destruction by repeated applications of pressure (fatigue failure) is a method less well known than the straight hydrostatic test. For a complete discussion of the fatigue tests of various types of pressure vessels, the paper presented in June of this year by Prof. H. F. Moore of the University of Illinois at the Detroit meeting of the American Society of Mechanical Engineers, should be consulted.

Table VI, which has been taken from Prof. Moore's paper, gives a summary of the test results of the various test shells and drums. Approximately 25 welded test shells and drums have been or are being tested to destruction under the repeated applications of a pressure corresponding to a stress cycle across the welded joint from a minimum of zero pounds to a maximum of 16,500 pounds per square inch in tension.

The fatigue test assembly used for the welded test shells is shown in Plate 8, the construction consisting of an outer shell, which is the shell to be tested, an inner shell forming an annular space between inner shell and outer shell for the application of hydraulic pressure, and packing glands at each end held in place by end plates. Several examples of the types of failure produced in the various test shells by this type of destructive test are presented.

Plate No. 9 shows the type of failure which occurred in a joint welded with bare electrodes by an operator of considerably more than average

skill. Failure occurred after 5530 applications of pressure, the failure being through the weld metal and evidently being determined by several imperfections along the line of fusion.

Plate 10 shows the fracture which developed in a shell welded with covered electrodes. The failure occurred after 267,000 applications of pressure along two separate elongated bodies of slag entrapped in the weld metal. This is included to show that while the reduction of the

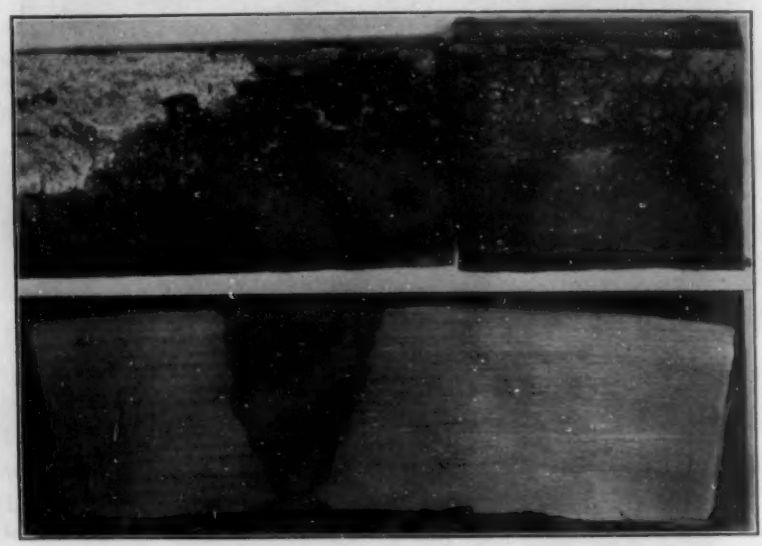


PLATE IX—(TOP) SURFACE OF FRACTURE DEVELOPED BY FATIGUE TEST IN WELD OF TEST SHELL, WELDED WITH BARE ELECTRODES. (BOTTOM) SECTION ACROSS WELDED JOINT IN ABOVE SHELL AFTER FATIGUE FAILURE, SHOWING PATH OF FAILURE. FAILURE DEVELOPED AFTER 5530 APPLICATIONS OF PRESSURE AT A STRESS OF 16,500 LBS./SQ. IN.

effective cross section by these slag bodies was relatively small, their effect in the production of localized highly intensified stresses was sufficient to produce failure under the fatigue test.

On test shells which had been welded by the special process and in which a ½ inch tapped hole for the hydraulic gage was present in the boiler plate, failure occurred not in the weld metal, but in the boiler plate through the tapped hole. Failure through the hole in the plate was due to a concentration of stress around the hole, the stress in the fibers of the plate around the hole reaching a possible theoretical value of three times the mean stress in the plate.

Plate 11 shows several views of the plug removed from around the gage hole in a test shell which failed in this manner. It is interesting to note that all test shells which failed through the tapped hole failed after 417,381 to 561,984 applications of a pressure, equivalent to 16,500 pounds per square inch stress in the plate. The range represented by these figures is quite narrow for tests of this nature, indicating that the effect of the tapped hole was more or less constant for all shells.

In the later test shells welded by the new process, there are no holes

for the hydraulic gage in the test shell proper, the hydraulic gage being connected to the inner shell of the fatigue test assembly. One of these shells has withstood 10,000 applications of pressure at 22,000 pounds per square inch stress in the shell and in addition 1,020,000 applications of pressure at 16,500 pounds per square inch stress. A second shell has withstood 1,995,450 applications of pressure at 16,500 pounds per square inch stress and in addition 50,000 applications of pressure at 22,000 pounds per square inch stress. No evidence of failure in either the plate or the welded joint is present in either shell.

A consideration of the above test results on both laboratory test specimens and full sized test drums should leave no doubt as to the quality of the welded joints produced by this process.

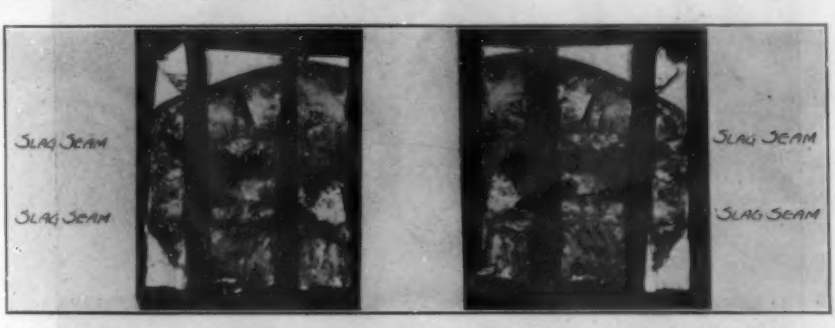


PLATE X—VIEW OF BOTH SURFACES OF THE FRACTURE DEVELOPED BY FATIGUE THROUGH WELD METAL. FAILURE DEVELOPED ALONG TWO ELONGATED SLAG INCLUSIONS IN WELD METAL

Test Procedure

A testing procedure governing the testing of the finished welded drum to determine the quality of the welded joint and the reliability of the structure is a subject on which considerable divergence of opinion may be expected and yet this phase of pressure vessels is of maximum importance.

A testing procedure which will absolutely guarantee the satisfactory performance of a welded pressure vessel under severe operating conditions must be made up of the following fundamentals:

1. The securing of welded test plates, which are obtained under conditions as near as possible to the conditions under which the main welded joints in the pressure vessel are produced. The determination of the tensile properties, the ductility under bending, the impact values, the macro and microstructural characteristics and the chemical analysis of the weld metal on specimens obtained from the above test plates. These properties must comply with the values of a rigid, yet reasonable, specification which will guarantee a high quality of weld metal.
2. The exploration of the main longitudinal and circumferential welded joints of the finished welded drums by an approved non-destructive test which would determine quantitatively the size and location of a defect within the welded joint.
3. The subjection of the completely welded drum or pressure vessel to a hydrostatic test pressure of some value considerably higher than the working pressure of the drum or vessel.

The testing of specimens cut from representative samples of the welded joint is very well understood and this method has been accepted by the Engineering and Welding professions in a general way. Difference of opinion exists only as to the details of this method; as to what constitutes a representative welded sample; as to what particular test should be made on specimens cut from the representative samples; and as to

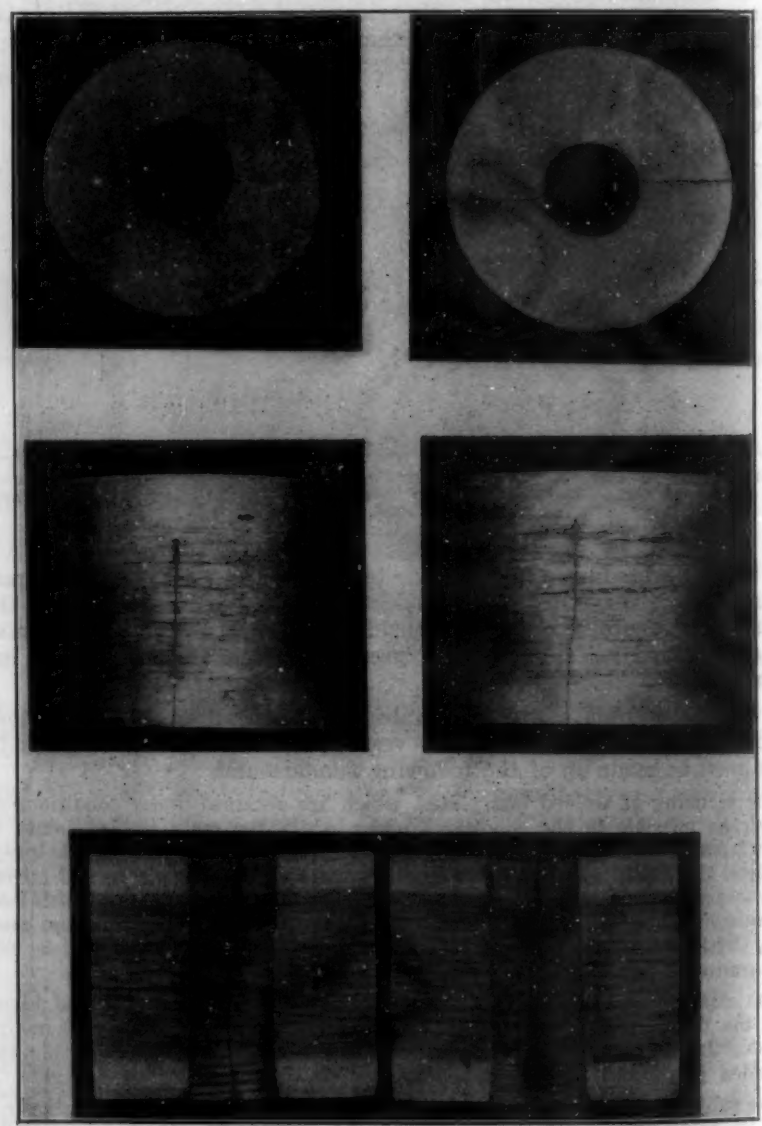


PLATE XI—VIEWS OF PLUG REMOVED FROM AROUND HYDRAULIC GAUGE HOLE THROUGH WHICH FATIGUE FAILURE DEVELOPED AFTER APPROXIMATELY 500,000 APPLICATIONS OF PRESSURE AT A STRESS EQUAL TO ONE AND ONE-HALF TIMES THE WORKING PRESSURE

what particular values the properties of the specimens should comply with.

The static hydraulic pressure test is also generally accepted, differences of opinion regarding this test being centered around the question as to what particular test pressure should be used. Should the test pressure be 1½ times the allowable working pressure of the vessel or should the

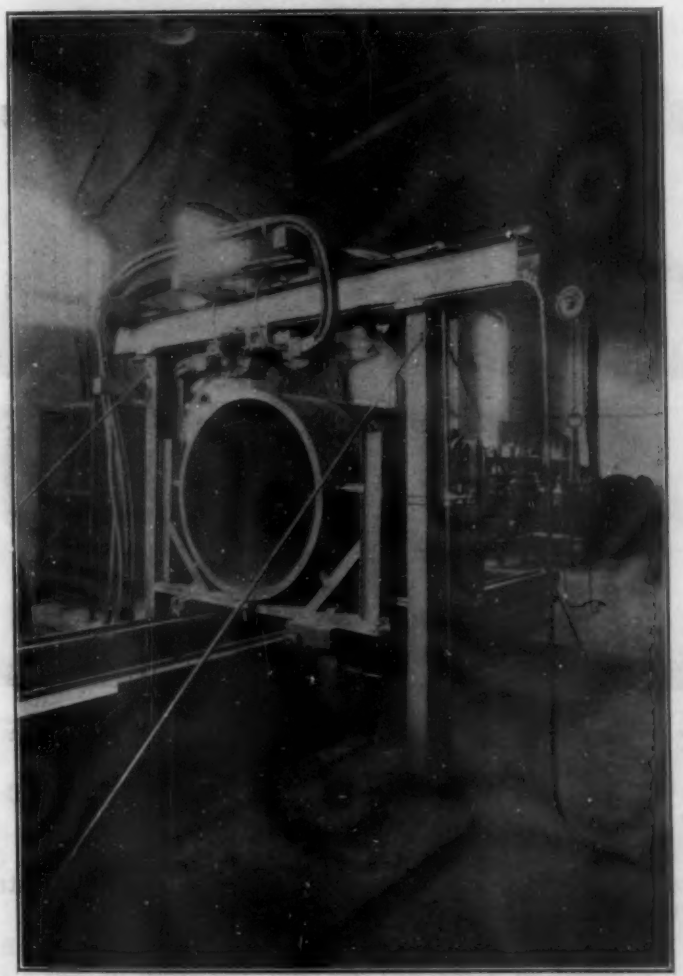


PLATE XII—EXPERIMENTAL SET-UP OF SPERRY APPARATUS

vessel be tested under a test pressure equivalent to a stress in the vessel in the neighborhood of the proportional limit or in the neighborhood of the yield point of the metal?

When we come to the remaining phase of the testing procedure for welded pressure vessels, namely, the non-destructive test or the explora-

tion of the welded joints of the finished welded drum, we find that there are no detailed data on non-destructive examinations of the welded joints of pressure vessels. There are several types of non-destructive test apparatus which may possibly be adapted to the testing of welded pressure vessels.

The development work on non-destructive test apparatus has been concentrated on two methods:

1. The fissure detection apparatus by electro-magnetic means, and,
2. The X-ray method.

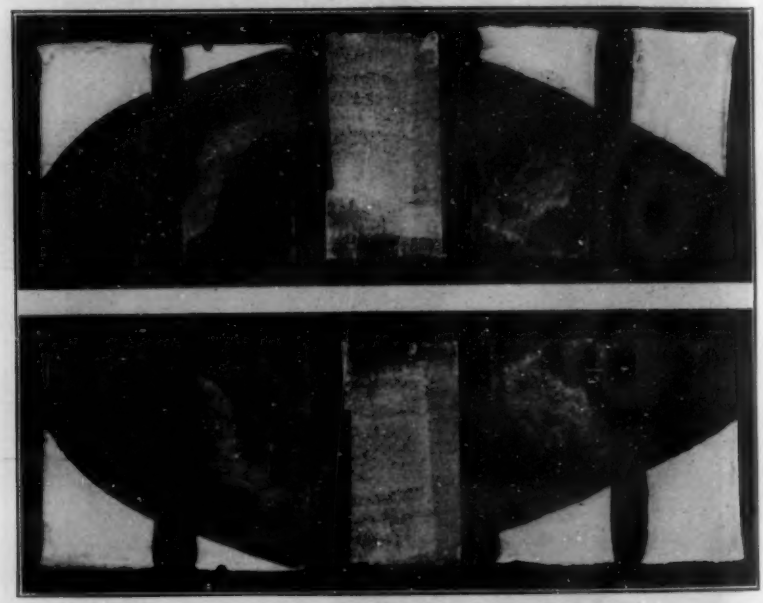


PLATE XIII—THE TWO SURFACES OF A CRACK IN A WELDED PRESSURE VESSEL. ACCURATELY LOCATED BY THE SPERRY APPARATUS AND ITS APPROXIMATE SIZE OBTAINED FROM THE RECORD

The first apparatus was designed by the Sperry Development Co., this apparatus being a modification of their fissure detector for rails.

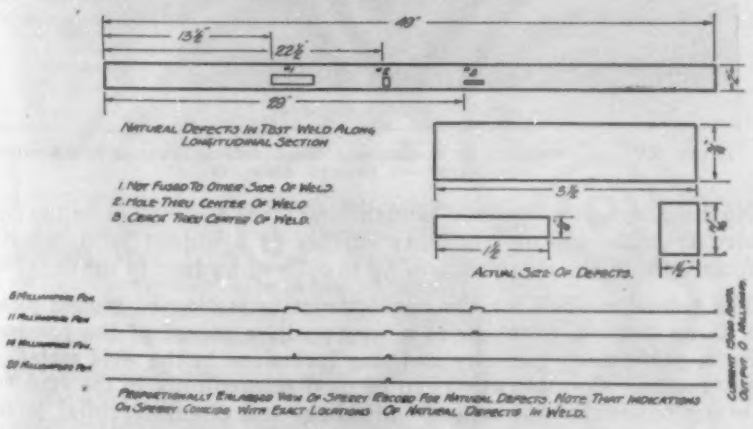
Considerable work has been performed in conjunction with the Sperry Development Co. in developing the application of this non-destructive test to welded pressure vessels.

Plate 12 shows the experimental assembly used. The test shell to be explored is placed on a movable platform, the speed of which can be readily adjusted. The drum is brought into contact with two brushes attached to the cross beam of the frame so that the welded joint of the shell lies between the two brushes. A heavy electrical D. C. current is brought into the brushes and passes through the welded joint. The current in the welded plate sets up a magnetic field around the plate and as the shell travels under the brushes, any deviation or distortion in the direction of current through the plate in passing around flaws or defects

within the welded plate causes a corresponding deviation in the direction of the magnetic field around the plate. The changes in the direction of the magnetic flux around the plate are detected and measured by a balanced coil unit, the changes in the current of which are amplified to control relays for the operation of the recording apparatus. In this manner a permanent record of the location and extent of flaws within the welded joint is obtained.

The Sperry apparatus readily gives an indication of the presence of a crack, which type of defect is indeed a very serious one. The location of the large crack shown in Plate No. 13 was readily discovered by the Sperry apparatus and its size was approximated from the Sperry record.

PLATE XIV—X-RAY APPARATUS FOR THE PRODUCTION EXAMINATION OF WELDED PRESSURE VESSELS



PROPORTIONALLY ENLARGED VIEW OF SPERRY RECORD FOR NATURAL DEFECTS. NOTE THAT INDICATIONS ON SPERRY CHART COINCIDE WITH EXACT LOCATIONS OF NATURAL DEFECTS IN WELD.

FIG. 3

An idea of the sensitivity and accuracy of the Sperry apparatus may be obtained by a consideration of the test results obtained on a weld containing defects. Fig. 3 shows the nature and approximate size of these defects. The records obtained from an examination of this weld by the Sperry apparatus were consistent in every case and checked perfectly with the measurements of the defects in the weld as is shown in Fig. 3.

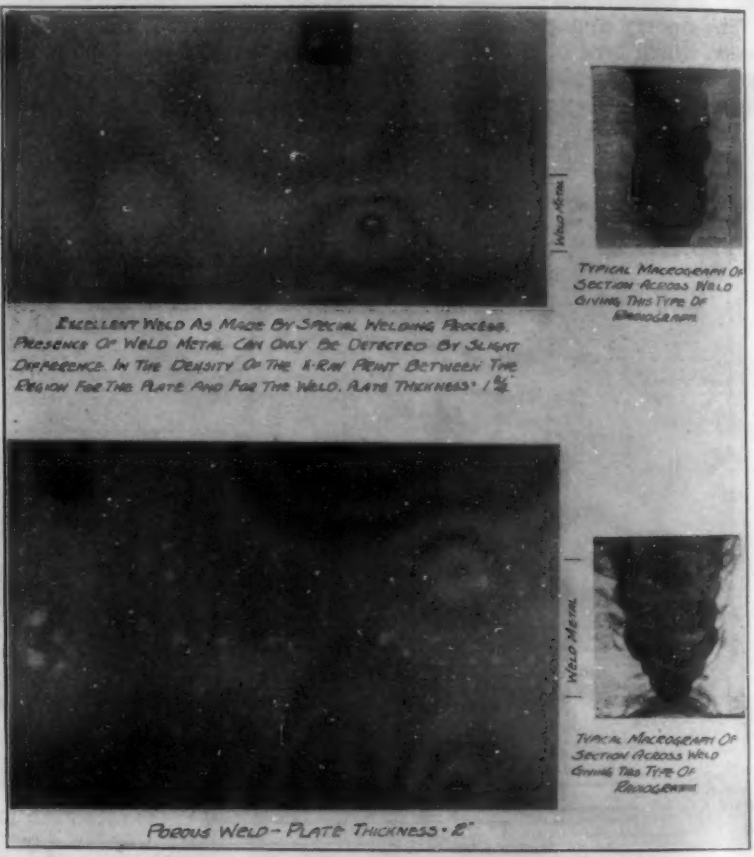

WELD METAL
TYPICAL MACROGRAPH OF SECTION ACROSS WELD GIVING THIS TYPE OF RADIOGRAPH
EXCELLENT WELD AS MADE BY SPECIAL WELDING PROCESS. PRESENCE OF WELD METAL CAN ONLY BE DETECTED BY SLIGHT DIFFERENCE IN THE DENSITY OF THE X-RAY PRINT BETWEEN THE REGION FOR THE PLATE AND FOR THE WELD. PLATE THICKNESS - 1/4"
WELD METAL
TYPICAL MACROGRAPH OF SECTION ACROSS WELD GIVING THIS TYPE OF RADIOGRAPH
POROUS WELD - PLATE THICKNESS - 2"

PLATE XV—RADIOGRAPHS OF EXCELLENT WELD AND OF POROUS WELD WITH CORRESPONDING ETCHED SECTIONS

No difficulty is encountered in obtaining large indications on the Sperry record from defects on the inner surface of a welded joint, where the defects were of the magnitude of ⅛ to 5/32 of an inch in depth.

The second method for the non-destructive testing of welded joints is the X-ray method, which gives a very positive record of the presence of defects, particularly porosity and slag inclusions in the weld metal. The X-ray method of examination can be used economically in the exploration of every portion of the main longitudinal and circumferential joints of a welded pressure vessel.

Plate 14 shows X-ray apparatus set up for the examination of a longitudinal weld in a shell 30 feet long with a wall thickness of 2¼ inches. The safety drum, X-ray power plant and controls are mounted on a track or car which is moved along the vessel for the examination of successive portions of longitudinal seams. For the examination of girth welds in the vessel, the vessel can be rotated about its axis. The X-ray tube is placed at a convenient distance from the outer surface of the vessel to be explored, the tube being mounted in a lead covered metal drum, pro-

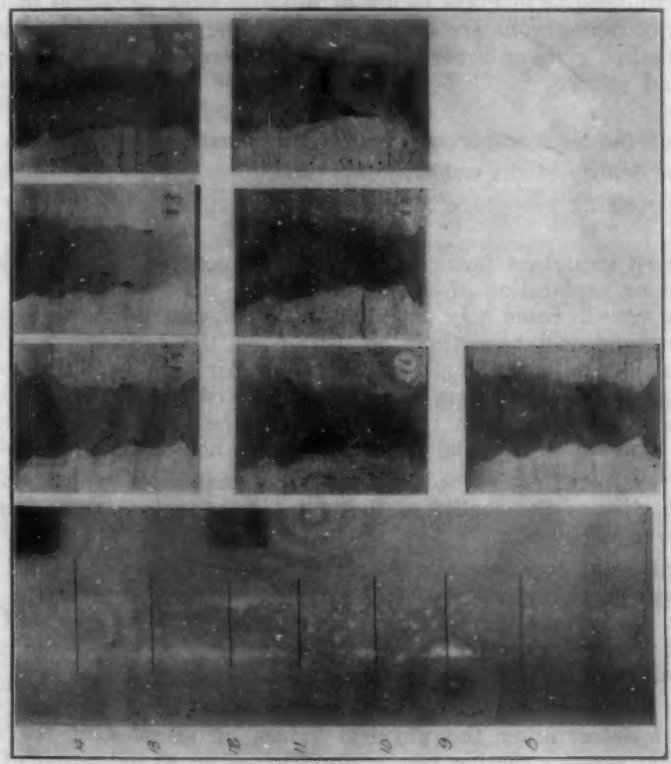


PLATE XVI—RADIOGRAPH OF POOR WELD SHOWING SLAG SEAMS ALONG WALLS OF WELDED JOINT. ALSO MACROGRAPHS OF SECTIONS THROUGH WELDED JOINT AT LOCATIONS INDICATED ON RADIOGRAPH

vided with a suitable window so that the rays reach only a limited region along and on each side of the welded seam. The auxiliary lead shields prevent scattered X-rays from escaping into the neighborhood. The film cut to a convenient size is placed near the inner surface of the vessel directly opposite the window of the tube drum and shielded with lead shields to prevent the escape of both direct and scattered X-rays.

The radiographs are made with a standardized technique in which all conditions affecting the character of the picture are held constant during the examination of each vessel. The voltage applied to the tube and the time of exposure are chosen to suit the wall thickness. For thicknesses

of 2 inches or more, 210,000 to 220,000 volts are used and the exposure time is chosen to give a satisfactory picture. For thicknesses below 2 inches an exposure time of two minutes is used and a reduced voltage is chosen to give a satisfactory picture. With a proper technique, cavities having a depth of 2 per cent of wall thickness are readily detected. If desired, a calibrating device consisting of a perforated sheet of steel of this thickness can be used to record on the film the difference in photographic density due to a cavity equal to 2 per cent of the wall thickness.

The radiographs in Plate 15 are of welds of varying degree of quality. The X-ray radiographs are self-explanatory and clearly indicate that the X-ray method gives an accurate and positive record of the defects present in welded joints.

CONCLUSIONS

Two of the most important phases of welded pressure vessels are:

1. The quality of the welded joints, and,

2. The testing procedure to be used in determining the quality of the weld.

The most important factor in the testing procedure is the non-destructive test or exploration of every inch of the main welded joint of the pressure vessel. Some may say that these non-destructive tests are unnecessary and will base their opposition on the consideration that if representative welded samples are obtained for each welded vessel, and if test specimens from these samples comply with the physical properties of the specifications, then the drum should be acceptable without any further examination of the welded joint by non-destructive tests.

However, securing welded samples, the quality of which would be representative of the quality of the main joints in the drum, presents a rather serious problem.

Regardless of how carefully we try to obtain samples of welded joints, which will be representative of the quality of the joints in the vessel, there is always the danger that the representative sample will be of excellent quality, while serious defects may be present at some location in the joints of the welded vessel.

As an accessory to the physical test specimens which offers only a means of determining the physical values of samples of the welded joints, the non-destructive test method gives an examination of every inch of welded joint, so that it is impossible for dangerous sections, regardless of how isolated they are, to be present in the welded joints of the drum. The time may come when non-destructive tests may not be necessary, but for the present and for some time to come, non-destructive tests are an absolute necessity in assuring the satisfactory performance of a welded joint in pressure vessel service for severe operating conditions. The non-destructive tests are the only means of examining the entire length of all arc welded joints in the drum to determine the presence or absence of dangerous defects, whether they are serious blow-holes, slag inclusions or cracks. The non-destructive tests must be considered as of major importance to the manufacturer of welded pressure vessels, to the user of welded pressure vessels and to the various governing groups of engineers charged with the supervision of pressure vessels to assure their satisfactory performance.

Shear Tests for Welds*

By Andrew Vogel†

WELDING, for the purpose of this paper, will be considered solely as a method of connecting steel members. As a connecting material it is subjected to shear, tension, compression and bending, or any combination of these forms of stress. This paper, however, will be confined to a discussion of welding in shear, and simplified test procedure for determining quality of welds and the unit stress values to be used in designing welding in shear.

Throughout the development or history of steel construction, almost invariably the connecting parts have been placed in shear because of the dependability of the connecting members, such as bolts and rivets, when subjected to this form of stress. As a result there has grown up a natural trend or habit resulting in the standard design of steel connections with the connecting members in shear. The first tests of welding placed the welds either in bending or tension, though sometimes in shear, but more often in a combination of stresses, making the test analysis so complicated that no accurate unit stress values were obtainable. The results were definitely harmful to the development of welding as it indicated connections of variable strength or created the impression that the strength of the connections was difficult of direct calculation.

Dependability in steel construction in buildings, structures, and machinery, is of the utmost importance and this dependability must be obtained by simple and direct methods. This requirement necessitates the use of welding in shear as much as possible and with the welds in such position that the unit shear on each weld can be directly and easily calculated. If, then, the necessities of design and construction determine the use of welding in shear, it follows logically that the *tests* of welds should be in shear in order to duplicate as nearly as possible the actual conditions under which welding is used.

Structural materials, in their various forms, necessitate shear connections. The building and mechanical trades are accustomed to shear connections. Inasmuch as conditions of materials and labor require shear connections, the tests should be made in shear in order to make direct comparison readily possible.

It is not always possible to duplicate service conditions exactly. Service conditions frequently require such large connections placed in such manner and on such shapes, that no test can duplicate or, on account of size, even approximate actual conditions. At present all that can be done under such circumstances is to arrange the welds so that the unit stresses can be accurately calculated, and depend on testing small specimens to

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†General Electric Company, Schenectady, N. Y.

determine the unit stress values which provide the proper factor of safety.

The facility with which shear welds can be applied to the structural shapes available results in economy of construction. The equal facility with which test specimens can be prepared for shear tests also results in economy. It is apparent, therefore, that both service conditions and testing conditions are peculiarly favorable to shear welds. In fact, the specimen to be used for shear tests, described on page 74 of this issue by the Committee on Standard Tests for Welds, illustrates a very simple and economical specimen which can be used not only to determine unit stress values for design purposes, but also to determine the skill and proficiency of the welder in field or shop.

It has already been stated that design methods are considerably simplified by the use of shear welds. A paper presented by the writer before the American Welding Society, April 25, 1929, entitled "Design of Joints for Welded Steel Structures" illustrates these methods in some detail, and a subsequent article has extended these methods. Design methods can be so simplified by the use of shear welds that the connections of a welded structure can be readily calculated by an engineer with assurance that the results will be satisfactory. And several tests of trusses used in construction and tests of individual connections have proved the accuracy of these methods of design.

The design of shear tests depends entirely on the results being sought. If it is desired to seek information regarding the qualifications of a welder, it is only necessary to prepare a specimen or series of specimens as illustrated in the bulletin of the Committee on Standard Tests for Welds. On account of the economy of these specimens, it is possible to test the welder's efficiency frequently, thus keeping an accurate record of the welder's workmanship.

Frequently it is desirable to have information on the efficiency of the members used in the structure as well as the unit stress value of the weld itself. In this case it is necessary to use angles, channels or other structural members welded to heavy plates with the amount of welding proportioned exactly as in the structure, and with all parts of the element to be tested designed to bring out the data sought for. This form of test is now being extensively used and the tests made to date have indicated that the method of analysis developed in the paper entitled "Design of Joints for Welded Steel Structures" has been entirely satisfactory It is necessary, however, in using structural steel shapes when testing welds in shear, to differentiate between testing to determine the efficiency of the members and testing to determine the unit stress value of the weld. This form of test is necessary, however, in connection with tests of shear welds in order to determine whether or not the strength of the shear weld is appreciably influenced by the shape of the member.

As experience in the testing of shear welds is accumulated the effect of position and length of welds may be more thoroughly understood. At the present time design methods are based on uniform stress throughout the length of the weld. Tests of riveted construction indicate that this may not be correct but experience to date in the design of sructures indicates that the use of uniform unit stress values is a proper procedure for all practical purposes.

The eccentricity of position of shear welds invariably produces shear in two or more directions on the same plane and this condition must influence the unit stress value in both directions. This form of shear test has not been carried out to a sufficient extent to determine accurately unit stress values. At the present time the resultant of shear in various directions on the same plane is limited to the unit stress value adopted for shear in one direction.

Experience has had considerable influence on the method of making shear tests on welds. At first the specimens were entirely too small, or rather the members were out of proportion with respect to the welds. The members distorted considerably before the welds failed and thus produced secondary stresses in the welds resulting in incorrect unit test values. The next series of tests was proportioned on the basis of keeping the stress in the members well within the elastic limit. The results were very satisfactory. The unit test values of the welds became uniform—so much so that it was possible to predict within a small percentage the load at which any test specimen would fail. In order to keep the stresses within the elastic limit the specimens were of quite considerable size in order to test a series of welds not over 6 in. in length. Later it was found that the specimens could be designed for welds of 1½ in. to 2 in. in length and that the unit stress values were approximately the same as for welds of 6 in. in length. It was also found that it was not necessary to machine the specimens and, therefore, rolled steel bars could be used.

The use of bar type specimens very considerably reduced the cost of tests and really placed the tests on a practical basis. This resulted in the recommendation to the Committee of a small bar type specimen which is submitted to you for your consideration, as the specimen to be used for determining the qualifications of welders and to provide more data for determining the unit values to be used in design. Of course, it will be necessaryy to test structural shapes also, but this work is really an extension of the problem which does not involve the welds at all but rather the efficiency of the particular structural shape under consideration. The problem may then be summed up by saying that experience has shown that bar type specimens with short welds are sufficient for the control of welders fabricating welded joints for steel structures.

The results of tests to date are given in an article by the writer entitled "Tests of Metal Arc Welds," published in the *General Electric Review*, June, 1929. This publication described a series of 173 tests, the conclusions of which have not been changed by a considerable number of subsequent tests. Time and space do not permit the republication of these data, but sufficient copies of this paper are still available for those interested. These tests can be summarized briefly as indicating the uniformity and reliability of arc welding, and the fact that the data published are sufficient for the design of steel structures. Of course, more tests will be made and these tests will amplify that knowledge and may even modify it, but a very considerable number of buildings have been completed with their design based on these tests. Many trusses have been tested, and the results have been uniformly satisfactory.

Shear tests can be summarized as being the type of tests which can be most economically performed and which duplicate most accurately the

conditions under which welds are designed and applied on steel structures. As the results have been satisfactory, it is recommended that the bar type specimen, illustrated by the Committee, be extensively used for the next year, and that the results of tests with the conditions surrounding them be sent to the Secretary of the American Welding Society for tabulation, analysis and publication. Probably by the use of this standard specimen over a period of a year, so much valuable information will be obtained that at the Annual Convention in 1931 it may be possible to approve or modify the specimen in order to make it the control specimen to be used to determine the quality of welds in shop and field for steel structures.

Shear Tests for Welds

APPENDIX A.

In order to illustrate the advantages of the standard specimen proposed for shear tests, as recommended by the Commiteee on Standard Tests for Welds, a series of twelve specimens was made. The specimens follow the standard proposed exactly. The series was divided into four groups of three specimens each, four welders of average ability were selected and each welder was directed to weld a group of three specimens. No special instructions were given, in order that the welds should indicate the average ability of each welder. The specimens were properly identified and taken to the Testing Laboratory. The tests were made in the usual manner and the results were recorded in the table blow.

Specimen	Total Stress	Stress per Linear Inch of Weld	Average Stress	General Average Stress
A-1	75,750	12,625		
A-2	81,300	13,550	13,217	
A-3	80,850	13,475		
B-1	81,400	13,567		
B-2	72,600	12,100	12,947	
B-3	79,050	13,175		
				13,253
C-1	88,050	14,675		
C-2	80,600	13,433	14,314	
C-3	89,000	14,833		
D-1	76,750	12,792		
D-2	76,700	12,783	12,536	
D-3	72,200	12,033		

It will be observed that the total load varies from 72,200 to 89,000 lb., or from 12,000 to 14,800 lb. per linear inch. The welds were of average quality, such as commonly used on steel structures; and as a design value of 3000 lb. per linear inch for $\frac{3}{8}$ in. welds is used, the result is a factor of safety of four or more.

The specimens were very economically prepared and brought out the ability of the welders in a very clear and satisfactory manner. In addition to indicating the character of work performed by each welder, it was very reassuring to find that all the work was of proper physical strength.

The results desired were obtained; that is, an economical specimen, simplicity in testing, fractures indicating character of work, and uniformly satisfactory physical strength proving the safety of the structures fabricated by qualified welders.

Why the Piping Contractor Prefers a Welded Job

By John J. Love[1]

Industrial steam piping installations are usually made today by means of oxy-acetylene welding. The advantages of welded construction for steam piping are numerous. The economies of a welded piping installation are apparent to the piping contractor from the start, owing to the simplicity in the designing for such construction. It is unnecessary to order special, odd-shaped fittings, as these specials may be made up in the contractor's shop or right on the job from standard pipe by the use of oxy-acetylene cutting and welding apparatus. The flexibility of this process is one of its greatest advantages in the fabrication of industrial piping.

The notable absence of heavy fittings and the consequent reduction in weight of the transmission piping is another great advantage to the piping contractor. We have found that the whole job is easier to handle and that the elimination of heavy fittings not only results in a reduction of material costs, but also reduces the cost of properly supporting the line. It is possible to locate piping in places where it would be impossible to make an installation were any other method used than oxy-acetylene welding. Welded piping may be easily installed in confined places such as pipe shafts, close to walls and in narrow tunnels.

The ease with which insulation may be applied to welded installations we find a great advantage. The line presents a smooth, uniform surface without uneven fittings, so that the covering can be applied at minimum expense.

The operating engineer will find a welded piping installation most satisfactory from the point of view of general plant operation. No projections or uneven joints interfere with efficient transmission, and there are dependable joints which are fully as strong as the pipe itself and usually stronger. The strong and ductile joint produced by oxy-acetylene welding is capable of withstanding the expansion and contraction stresses caused by the varying temperatures in the piping.

The welded joint is the most satisfactory joint for resisting corrosion, and the fact that it is leak-proof adds an assurance that there will be no loss of power through the development of leaks and minimizes the possibility of a shut-down for repairs.

Alterations on piping systems already in operation may most effectively be made by means of the oxy-acetylene process, and these changes can best be made on welded lines. When an additional branch or connection has to be made on the line, the necessary outlet is cut according to a templet with a cutting blow-pipe and the new connection is welded in in a very short time so that the shut-down is reduced to a minimum. The

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flexibility of the oxy-acetylene process is a vital factor both in initial installations and in additions to existing piping systems.

We have made a great many steam piping installations in the vicinity of Philadelphia, all of which have been oxy-acetylene welded throughout. Recently we were called upon to do a job which has attracted considerable attention.

FIG. 1 — WELDED EXPANSION LOOPS IN 12 IN. AND 6 IN. PIPE FOR 300 LB. STEAM PRESSURE

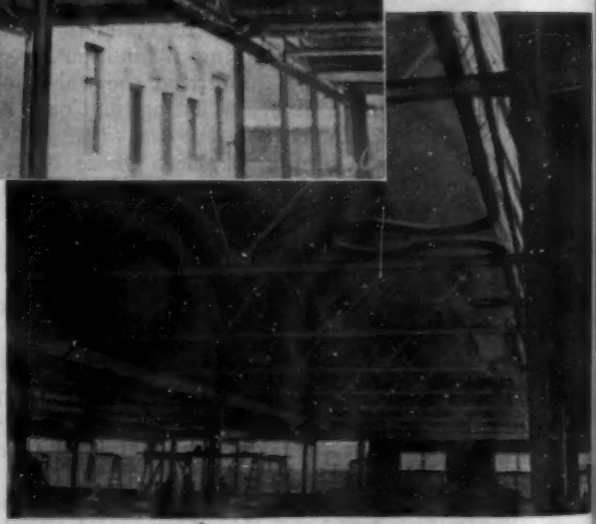

FIG. 2—OMEGA BENDS 6 IN. AND 2 IN. PIPE

A large manufactourer of radio equipment recently constructed a complete new plant addition, which also involved the installation of a new steam piping system. Oxy-acetylene welding was specified as the method by which the pipe should be installed, and our company was awarded the contract largely because of our familiarity with welded piping installations.

The essential features of this installation were a 12 in. steam main designed to carry 300 lb. per sq. in. pressure, and a series of smaller lines of 8 in., 6 in. and 4 in. pipe fed by the 12 in. main. Fig. 1 shows this 12 in. line paralleled by a 6 in. line, with expansion loops in each of the lines. Because of its size, the 12 in. expansion loop had to be shipped in sections, which we welded together on the job.

Fig. 2 shows other expansion loops in a 6 in. line paralleled by a 2 in. line. It is interesting to note that the same principles were followed in constructing the small diameter lines as in the larger sizes. In the 2 in. line all of the joints are made by oxy-acetylene welding just as in the larger sizes of pipe.

Reducers were necessary at several points in the system. Fig. 3 shows an eccentric reducer joining 12 in. and 10 in. sections of the line.

FIG. 3—SWAGE JOINTS FROM 12 TO 10 IN.

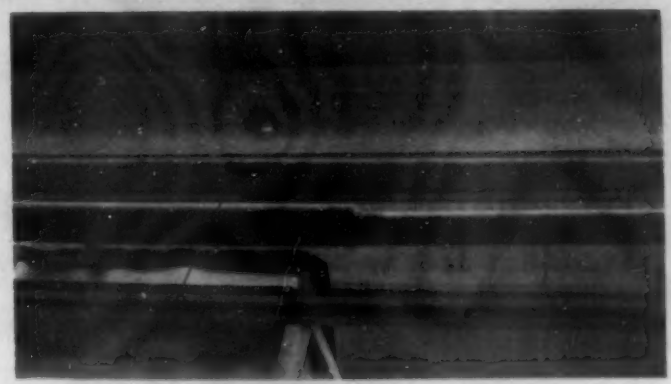

FIG. 4—6 IN. TO 4 IN. REDUCER

We use this type of reducer for small changes in diameter. It is made by heating the end of the larger pipe with the blowpipe, swaging the heated section down to match the smaller pipe. The reduced end is then welded to the smaller section of the line. Fig. 4 shows another reducer between 8 and 6 in. pipe. This view was taken looking almost straight up at the roof. Eccentric reducers were used throughout this installation as they avoid the possibility of having pockets where condensate might collect.

Another feature of this installation was the use we made of short radius bends specially fabricated for welding. Fig. 5 shows these bends used in 6 in. and 8 in. risers from the 8 in. main. These bends consist of seamless steel tubing hot-formed by machine on a special mandrel to give curves having a radius of only 1½ times the diameter of the pipe. These short radius bends are designed especially for welded construction and are furnished with beveled ends. The usual bends, such

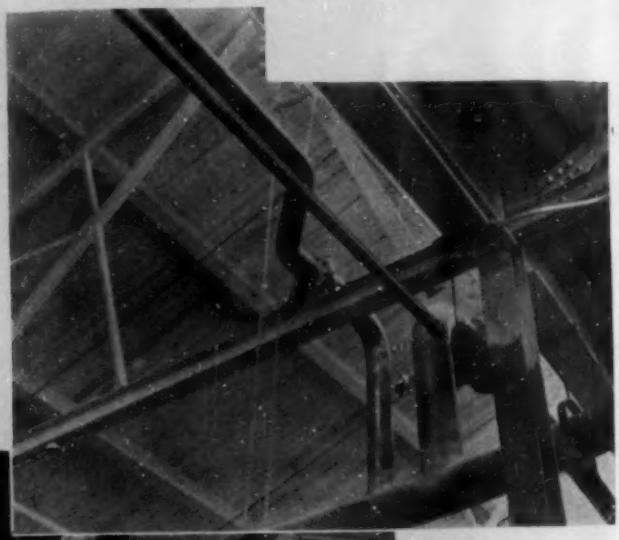

FIG. 5—WELDED SHORT-RADIUS BEND.

FIG. 6—FLANGE CONNECTIONS USED NEXT TO VALVE

as the ones shown in the illustrations, are 90 deg. elbows, but these may be altered to make a bend of any size by cutting off enough of the turn to make the required elbow. No matter where the cut is made the end will be a perfect circle. In the 6 in. line a welded offset is shown which brings the pipe back under the beam from which it is to be supported. Short radius 90 deg. bends cut in half were used for making these two 45 deg. bends.

Fig. 6 shows these same two risers from the 8 in. main from the other

side. It will be noted that both of these branches have valves at this point. In seam piping, it is usually necessary to use flanges on the line next to valves, and occasionally at other points where it might become necessary to disconnect the pipe. It will be noted that at all other points in this installation flanged connections are eliminated.

Fittings or connections of the type shown in Figs. 5 and 6 were fabricated right in the plant where the installation was being made.

Part of the work on this installation involved the laying of new steam mains under the street out-of-doors to connect the new plant with the old power plant.

All of the welding was done in accordance with the established principles of procedure control and the completed installation not only presents a most workmanlike appearance but will give the owner perfect service throughout its life.

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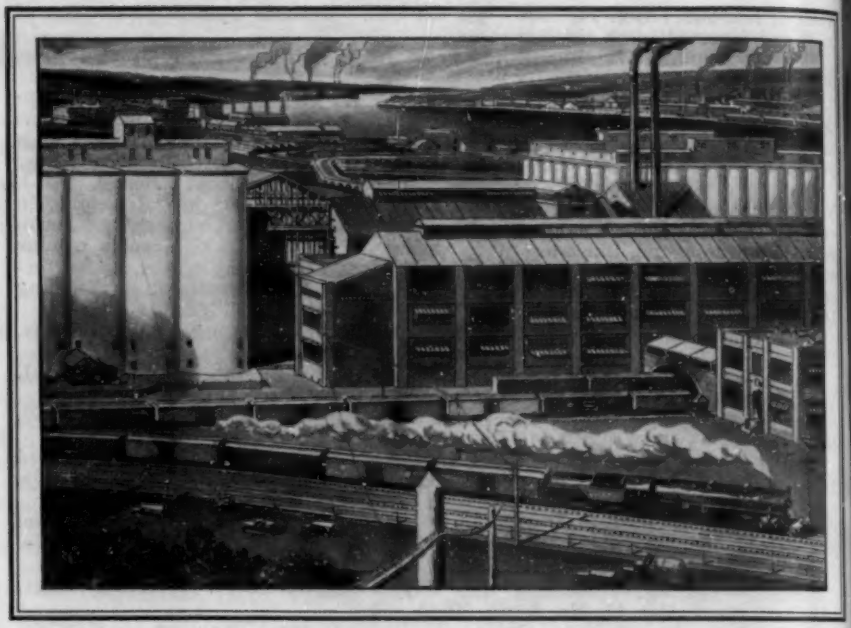

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